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PROTECTION AND CONSERVATION OF THE WATER RESOURCES OF PENNSYLVANIA[1]

BY

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It is a great honor as well as a great pleasure to have this opportunity to tell you ladies and gentlemen something of the progress that has been made in conserving Pennsylvania's water resources during Governor Duff's administration. I am somewhat surprised at the number of people who apparently consider the primary purpose of this work is to improve fishing, to improve the scenery or to provide recreation. But, as someone said, you can't drink fish, and you can't live on scenery. The basic reason for this program is that water is essential to life, communities, to industries, and water conservation now will mean dollars and cents to the present, and to the future citizens of Pennsylvania.

Our knowledge of today is but a compilation of the knowledge of the past. History tells us of lands of milk and honey, of lands of plenty. Ding Darling, the cartoonist, in speaking of these same lands, says that today a self-respecting South Dakota grasshopper could not find sustenance on 100 acres. In speaking of Asia, Mr. Egon Glesinger, a Forestry expert of the United Nations, says, "The appalling poverty of Asia can be traced to the misuse of its forests. As the forest disappeared, the headwaters dried up, the rains washed away the mountain top soil and erosion took its toll."

Right here on our own continent we have the ruins of a once great Mayan civilization.

History is replete with the rise and the decline of various civilizations. But history is of no value to us, unless from it we learn the

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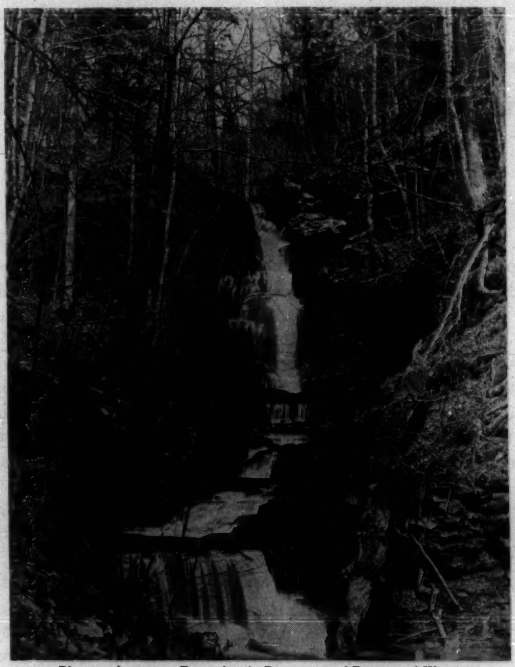
reasons for the rise and for the subsequent decline of these civilizations, and use that knowledge to guide our own future.

Briefly, I believe it can be shown that the rise of these civilizations was during the period when ample resources were available and that the subsequent decline coincided with the depletion of those natural resources.

The United States is a great country, but as with the countries of the past, our strength has been, and is, our abundance of natural re-



Photograph courtesy Pennsylvania Department of Forests and Waters

Clear, clean streams were our heritage.

sources. Natural resources are the basis, the very foundation of our economy. Industry is but the processing of natural resources, the adapting of those resources to sizes and shapes suitable for our use. In spite of the fact that natural resources are the foundation of our economy, the very abundance of these resources has led us into wasteful habits and ways and there is no denying the fact that we have been grossly prodigal in our resources.

When the first settlers came to Pennsylvania they found the land covered with forests, the streams were clear and clean. Three hundred years is but a very brief span in the life of this continent, and yet in that 300 years the virgin forests have been cut and the streams polluted with all sorts of human and industrial wastes.

As little as 50 years ago here in Pennsylvania prime hemlock and prime oak, trees that had been growing for more than a century, were cut that their bark could be used in the tanneries, and the logs left to rot where they fell. We have done what seemed expedient at the moment, with no apparent thought of the future. We are following

Photograph courtesy Pennsylvania Department of Forests and Waters

Civilization makes its mark on the streams.

the same road as the Asiatics—the road to poverty through depletion of our forest and water resources. Today, our attitude toward the streams of the Commonwealth is the same as the attitude of the earlier wasteful woodsman who cut the trees merely to harvest the bark. Many streams of Pennsylvania are now so polluted as to preclude their use for human consumption or for use in many types of industry. After years of having used the streams as a means of disposing of wastes, many people question the necessity of now doing otherwise. The answer lies in our increased and increasing population.

We think of China as a land of dense population. According to the State Department of Commerce, China has 115 persons per square

mile; Pennsylvania has 230—twice that of China. The population of Pennsylvania doubled between 1890 and 1950. The situation is further complicated by the fact this increase in population is primarily urban, that is, in congested areas where even today the demand for water puts a strain on the available supply. It is estimated that in another 50 years the population of the United States will again be doubled. Enlarged communities will require more water.

In order to provide employment for this increase in population, industries will require vast quantities of water in their processes. At the same time, the increase in population and the even greater increase

Photograph courtesy Pennsylvania Department of Forests and Waters

Dredging in the upper Schuylkill.

in industry has increased our wastes. In a recent article, the author stated that each year domestic and industrial users dump into the Nation's streams, waste and sewerage equal in weight and offensiveness to the carcasses of 8 million mules. So that we find ourselves in a situation where on one hand, the demand for more water increases by leaps and bounds, while on the other hand, by polluting our streams we are destroying the very sources upon which eight-tenths of the population of Pennsylvania depend for their water supply.

The supply nature gives us is limited. The problem is to protect and preserve our limited fixed supply and to stretch this supply to serve more people and still more people.

Secretary Roosevelt, of the Department of Commerce tells me that one of the first questions asked by an industry seeking a possible location in Pennsylvania is "What assurance can you give of a supply of water?"

It seems clear that the cardinal factor which will limit the growth and the expansion and determine the prosperity of any area is water. Water is the one resource without which we cannot live. It is the one resource for which there is no substitute. As one writer states "truly water is to the land as blood is to the human body." The fact that industry can no longer rely on underground water as an assured source of supply emphasizes the importance of improving the quality of water in our streams.

Photograph courtesy Pennsylvania Department of Forests and Waters

Discharge from dredge in the Schuylkill River.

There is a very definite relationship between water and forests. The humus, the rotting leaves and branches, in a forest absorb the rains somewhat as a sponge, retarding the runoff which causes floods and thus it gives the water more time and opportunity to percolate into the soil to replenish underground waters.

As the sustained flow of our streams is the flow of thousands of small springs over the watershed, any reduction of underground water that supplies these springs means a reduction in the sustained flow of the stream. In a recent experiment to determine the effect of ground cover on water, the U. S. Forestry Service selected three plots, one with

good ground cover, one with fair ground cover, and one with poor ground cover. On the plot with poor ground cover the immediate run off was more than twice that of the plot with good ground cover. This rapid runoff means less water could percolate into the soil. But even more serious is the fact that the amount of soil eroded from the plot with poor ground cover was more than 25 times the erosion from the plot with good ground cover.

We, in America, have always felt free to do more or less as we pleased. However, courts have long taken cognizance of the fact a man was not free to do entirely as he pleased if his action harmed his neighbors.

The State of Washington's compulsory reforestation law recently was tested and upheld in the Supreme Court of that State and in the United States Supreme Court. The Washington State Court stated, "The inviolate compact between the dead, the living and the unborn requires that we leave to the unborn something more than debts and depleted natural resources." In commenting on the decision of the United States Supreme Court, the Secretary of the Interior of the United States said, "The importance of this decision lies in its endorsement of the theory, still somewhat novel to most Americans, that private owners of the Nation's renewable natural resources do not have the unqualified liberty to use and destroy them as they see fit. The Court has held, in effect, that they bear a deep responsibility to the Nation as a whole, and to generations yet to come, and that if they do not recognize this responsibility the State has the right and the duty of forcing it upon them." The renewable natural resources are our forests and our streams.

Most assuredly then, the Commonwealth cannot afford to neglect the duty of protecting its streams which are the property of all its citizens.

The Secretary of the Interior further stated "The problem is so urgent and of such importance to the welfare of the Nation that if the individual forest land owner is too lazy, shortsighted, or indifferent to act, and if the States are unwilling to act, the Federal Government will have to enter the picture with increased vigor."

The only source of funds from which a Federal program for pollution abatement could be financed is taxes. If the Pennsylvania policy of each state handling the pollution problem within its own borders were to be followed, there would be no need for action by the Federal Government, or for additional drain on the Federal Treasury.

The problem of preventing pollution from entering the streams of the Commonwealth falls to the Sanitary Water Board of which I am a member. The Chairman of that Board, a fine gentleman whom many of you know, is Dr. Norris W. Vaux.

The Sanitary Water Board had a very important part of the Schuyl-

kill River Project in the preventing of new mine wastes from entering the stream. Every one of the colleries on the Schuylkill Watershed now has a sedimentation basin or other treatment works in operation and the discharge of new mine wastes to the stream has been stopped.

In addition to the work on the Schuylkill, a notable result of preventing mine wastes solids from entering a stream is Swatara Creek on the Susquehanna watershed. Swatara Creek is the source of water supply for the borough of Hummelstown. The engineering firm in charge of the Hummelstown water system reports that they are now using 70

Photograph courtesy Pennsylvania Department of Forests and Waters

Dredging the Schuylkill River.

per cent less of one corrective chemical, 30 per cent less of another, and that together with the improvement in the quality of the water that requires less chemical treatment, the quality of the water in the Hummelstown water system is now better than at any time in the past 40 years. As a result of the Schuylkill Project, Pottstown and Philadelphia both report a substantial saving in the treatment of water.

In the field of sewerage, probably the greatest single item of progress during this administration has been the development of the Allegheny Sanitary Authority. In the Pittsburgh area the contour of the land and the industrial congestion made it either impracticable or impossible for the various communities to construct their own treatment works.

Fifty seven communities including the City of Pittsburgh have signed contracts with the Allegheny Sanitary Authority wherein their sewerage will be collected and treated in a master plant.

Of more local interest is the organization of an authority in the City of Bethlehem. The untreated sewerage of Bethlehem was discharged into the Lehigh River, and hence entered the Delaware. Bethlehem is financing the construction of its treatment plant, through an Authority whose bonds bear a low rate of interest of less than 2 per cent.

Philadelphia is financing the construction of its treatment plants through a sewer rental charge. The financing of the construction of

Photograph courtesy Pennsylvania Department of Forests and Waters

Pumping the Schuylkill River into Sanatoga Basin.

sewerage treatment plants boils down to a simple fact expressed by the old adage "where there is a will there is a way."

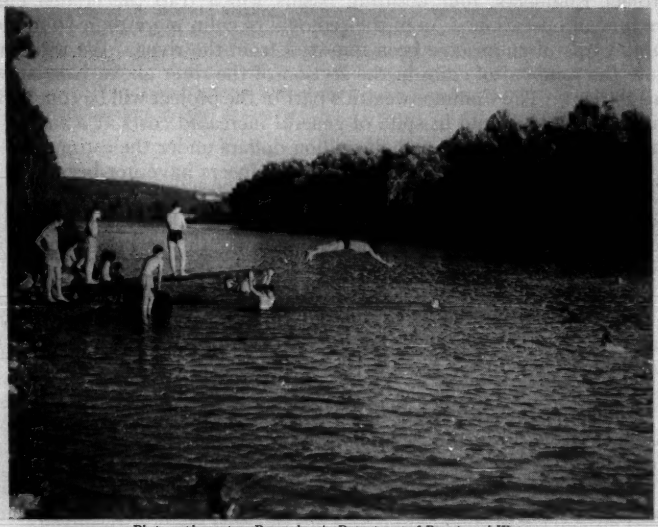
In the field of industrial wastes, standards of the quality of the wastes that may be discharged to the stream by a number of industries, have been established.

These standards have not been set arbitrarily. They have been set in consultation with the industry concerned and are acceptable to the industry as well as to the Sanitary Water Board. That industries should cooperate with the Board in accepting these somewhat rigid standards is indisputable evidence that industry realizes that the present

rate of pollution cannot continue without the industry itself being jeopardized.

Projects which have an effect on water, be they pollution abatement, soil conservation, reforestation or flood control are a genuine benefit to all of the people of Pennsylvania. It is impossible to overemphasize the great importance of these programs on the future.

Due to our wealth in resources this is a great country, a strong country. But today no country can expect to be strong, no country can expect to have this extensive industrial development unless it has the water to supply the needs of industry and the needs of the people



Photograph courtesy Pennsylvania Department of Forests and Waters

Recreation returns to the Schuylkill.

who operate these industries. With clear water we can have growing communities, growing industries, more employment, more recreation, prosperity. With foul water—stagnation, low employment, dying cities, depression lie ahead.

Guard your water resources, guard the most valuable of all our natural resources that America may remain the land of opportunity for the generations to come and that the future may be bright for the Pennsylvania of your children's children.

The largest stream clearance project in the Commonwealth is the Schuylkill River Desilting Project. In brief, the Army Engineers'

plan said "stop the entrance of new mine wastes to the stream, trap the culm that will erode from the spoil banks throughout the drainage basin and remove the culm from the river, and you will have clear water." The difficult part of the project was how to carry out the plan. Though the breakers were discharging approximately two million tons a year to the stream, the entrance of new mine wastes has been stopped. The Schuylkill River Basin contains a large part of the Southern Anthracite field. Throughout the basin are innumerable culm piles or banks of mine waste that will erode into the stream.

Thanks to the ingenuity and the efficiency of the Schuylkill River Project Engineers, four desilting basins which trap the eroded culm are now in operation. As to the removal of culm more than 16 million cubic yards of culm have been removed from the river. We will complete the removal of culm in the section of the river above Norristown this Spring. The Commonwealth's part of the project will be completed ahead of schedule and in spite of general increased costs at a saving of approximately one and one half million dollars under the estimate.

I regret very much that the Army Engineers have not been able to proceed with their part of the project—that is the dredging of the section between Norristown and the Fairmount Dam. However, the work that has been done by the Commonwealth has been a material benefit to the whole Schuylkill Valley.

Here at Philadelphia the amount of solids in the water pumped at the Belmont station now contains but two-fifths of the amount before our work started. One has but to observe the water flowing over the Fairmount Dam to see the result of the work on the upper reaches of the river.

When the President's Advisory Board on Pollution Abatement inspected the work on the Schuylkill, one member stated: "In order to appreciate this job, it must be seen."

However, from the figures in this paper, I trust you can obtain an idea of the sad condition of the river before work was started and something of an idea of the work which has been accomplished in building the desilting basins, the dredging and the disposal of the dredged material.

TRANSIENT ANALYSIS OF THREE-PHASE POWER SYSTEMS, PART I*

BY

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SUMMARY

The application of symmetrical components to the solution of steady state problems in power systems engineering suggests the application of the same or similar components in the study of transient phenomena on the network calculating board by means of oscilloscope and synchronous switch. However, it is found upon rigorous examination that symmetrical components are applicable to such problems in but a few types of switching. Part II of this paper will deal with a system of components which serve well in all cases of transient phenomena produced by short circuits, the operation of circuit breakers or other apparatus.

A. INTRODUCTION

The study of three-phase systems operating under unbalanced conditions has been made simpler and clearer by the use of a set of variables replacing the original three-phase quantities. The transformations between the two sets of variables are linear and lead in the most common case to symmetrical components (1);[3] other methods have also been applied very successfully (2). These methods have been in use for some time to study steady-state unbalanced conditions. For the more complicated analysis of complete power systems, these methods are used in conjunction with a network calculator (3,4). During the last decade the analysis of transient conditions has become important, since it became evident that it was necessary to predict system recovery voltages (5–13). A method devised by Turner (14, 15) has allowed the use of the network calculator in transient studies (13). These studies have been made on a miniature three-phase systems set-up on the calculating board.

The question arises whether the new components replacing the three-phase quantities also apply to transient conditions for it may be desirable to set up single-phase circuits on a calculating board rather than the entire three-phase equivalent, particularly in the case of existing calculating boards acquiring additional equipment in order to conduct transient studies. It is the purpose of these papers to discuss this

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[3] The boldface numbers in parentheses refer to the references appended to this paper.

question and show some of the circuit representations required for the transient study. Since the methods of the Laplace Transform and Fourier Transform (16) in transient solutions are essentially similar to the ordinary method using rotating phasors to find steady-state solutions in electrical circuits, one would expect any of the methods using substituted variables to be applicable to transient problems. A rigorous extension of symmetrical components has been attempted by Pipes (17, 18) who has been successful although he has failed to point out the pitfalls of the symmetrical component method when applied in collaboration with a network calculating board to find the transient solution. The reasons which make it undesirable to use symmetrical components will be pointed out in this part, and it will be shown in Part II that all difficulties are avoided if alpha, beta, zero components (or Clarke-components (2)) are used.

Previous analytical work done along these lines has been attempted in France by the late J. Fallou (19), who used symmetrical components in an analysis of traveling waves on three-phase lines, by Bekku (20) in Japan and Satoh (20), although their work made no specific use of either type of components, and in this country by Pipes (17, 18) as mentioned before.

B. SYMMETRICAL COMPONENTS WILL NOT DO FOR TRANSIENT ANALYSIS

The usual problems of three-phase power frequency circuits dealt with by symmetrical components are those considering the effect of short circuits or faults on transmission lines. Some sort of sequence representation of the system is made which has no mutual coupling elements and is a single-phase equivalent. The sequence networks are interconnected at the point of fault in a definite manner corresponding to the type of fault. Currents, voltages, and powers in the sequence networks are then determined either analytically, or as is usually done, these quantities are read by meters on a network calculator. Present interest shall be with the latter method.

The generating units appear in the positive sequence network in the symmetrical component equivalent. As many generators are present in the positive sequence network as in the actual three-phase system. However, this is not convenient if there are a great number of generators in the system. The effect of the fault can easily be found by utilizing the superposition principle of electrical circuits (21, 22). If the pre-fault voltage of the sequence networks at the point of fault is applied at this point with all other generating sources short circuited, then the changes in voltage and current, due to the occurrence of the fault, would appear. The total of each of these quantities appearing during the fault will be the sum of the changes and the pre-fault values. For transient analysis a switch would be inserted which would connect the sequence networks and a voltage source (which represents the pre-fault

voltage) together at the proper time and in the proper manner to represent the given type of fault.

However, another type of transient problem is important and this concerns the opening of circuits. When the fault is cleared, perhaps by a protector tube (23) at or near the point of fault, the use of a method to find the changes produced by the opening requires the application of a current generator which supplies the system from the point under question with the current which would have been present if no opening had occurred. This can be done analytically; however, in practice it is difficult to construct a current generator. If the opening occurs before the initial transient has died out the current requirement will not even be sinusoidal. Thus calculating board solutions based on an equivalent source are not possible so that all generators must be used, and the fault simply represented by the opening and closing of a switch.

The following will be concerned with symmetrical component representation and three important difficulties with this type of representation will be shown. The results will bear out the fact that symmetrical components cannot generally be employed for transient studies on a network calculator. The type of transformation which is involved in symmetrical components includes the complex numbers $\exp(\pm j120°)$ and requires that the circuit quantities be represented as rotating phasors. In transient analysis the phasors may vary in magnitude in addition to rotating about an origin. Some phasors will be stationary, corresponding to a direct current term. At any time, the instantaneous expression is the sum of the projections of the phasors on either the vertical or the horizontal axis. Suppose, now, that the transient study using the sequence networks has been made. The results are a set of oscillograms of the sequence quantities. To determine phase a quantities, it is merely required to add the various sequence quantities. To determine phase b or phase c quantities, the positive and negative sequence quantities are multiplied by $\exp(j120°)$ or $\exp(-j120°)$. From ordinary circuit theory it is known that the transient result will contain a steady-state term and a series of (usually) decaying terms which are dependent upon the initial conditions. Then it is possible to write an expression for an instantaneous sequence current (say) as

$$i = A \sin(\omega t + \phi) + \sum_{m=1}^{n} B_m F_m(t) \sin\theta_m \sin(k_m t + \zeta_m), \qquad (1)$$

where

A = the magnitude of steady-state term.
$B_m \sin\theta_m$ = a magnitude dependent upon initial conditions.
$F_m(t)$ = an indication that the quantities vary with time.
k_m = the natural frequencies of the system.
ζ_m = the phase angles.
n = the number of terms appearing in the transient expression.

Consider that this expression must be multiplied by exp ($j120°$). First it must be changed to rotating phasor form, so letting I be the rotating phasor expression for the current

$$I = A\epsilon^{j(\omega t+\phi)} + \sum_{m=1}^{n} B_m F_m(t)\, \epsilon^{j\theta_m} \sin(k_m t + \zeta_m), \tag{2}$$

then multiplying

$$H = \epsilon^{j(2\pi/3)} I = A\epsilon^{j[\omega t+\phi+(2\pi/3)]} + \sum_{m=1}^{n} B_m F_m(t)\, \epsilon^{j[\theta_m+(2\pi/3)]} \sin(k_m t+\zeta_m) \tag{3}$$

and in instantaneous form

$$h = A \sin\left(\omega t + \phi + \frac{2\pi}{3}\right) + \sum_{m=1}^{n} B_m F_m(t) \sin\left(\theta_m + \frac{2\pi}{3}\right) \sin(k_m t + \zeta_m). \tag{4}$$

Thus knowing the total expression for i it is required to find h. Since only the entire expression is known as an oscillogram, it is easy to see that B_m, $F_m(t)$, θ_m, k_m, and ζ_m are unknown and cannot be found from the oscillogram alone. The change in the steady-state term amounts to translation of this term on a fundamental frequency time basis. The change in the transient terms amounts to a change in magnitude (generally different for each term) which is given by increasing the argument of a term dependent upon the initial conditions. Thus the problem of determining h amounts to determining $\sum_{m=1}^{n} C_m(t) \sin(\theta_m + 120°)$ when only an oscillograph of $\sum_{m=1}^{n} C_m(t) \sin\theta_m$ is known. No simple relationship between these quantities is known nor does one exist.[4] Proceeding along another line and expanding we find

$$\sum_{m=1}^{n} C_m(t) \sin(\theta_m + 120°) = \cos 120° \sum_{m=1}^{n} C_m(t) \sin\theta_m + \sin 120° \sum_{m=1}^{n} C_m(t) \cos\theta_m. \tag{5}$$

The first term on the right hand side of Eq. 5 is known and the second amounts to a change of initial conditions by ninety degrees. A quantity proportional to the second term can be found by either opening or closing a switch (to represent the fault conditions) ninety degrees later on a fundamental frequency time basis than when the change did occur. No trouble will come about in closing the switch but the opening may be required to interrupt a finite current in zero time.

[4] A mathematical proof appears in the Appendix.

The difficulty brought about by the multiplication by the complex operator is eliminated if the operators can be combined in the expression for phase b or c quantities. This can be done if (and only if) positive sequence and negative sequence quantities are equal. The criterion is the same as saying that phase b or c quantities should be equal. Assuming that the system is symmetrical or that positive and negative sequence impedances are equal, then only exceptions to the difficulty just outlined are single line to ground faults and single open conductor faults since here the changes of currents and voltages are the same in both sequences. So for these we may write for currents[5]

$$\begin{aligned} I_b &= I_0 + \epsilon^{-j(2\pi/3)} I_1 + \epsilon^{j(2\pi/3)} I_2 = I_0 - I_1, \\ I_c &= I_0 + \epsilon^{j(2\pi/3)} I_1 + \epsilon^{-j(2\pi/3)} I_2 = I_0 - I_1. \end{aligned} \tag{6}$$

A similar relationship applies to voltages. Of course, since this can be applied only to the changes then some way must be found of getting only the changes. It was stated before that a difficulty arises in considering opening circuit conditions and as a result any oscillogram obtained will include the entire quantity and not just the change in it. As a specific example, consider a single line to ground fault occurring and the subsequent opening by a protector tube. At the instant of fault a switch closes and the three sequence networks are placed in series. Considering currents then, the current in the negative sequence network is just the change of current in this network. The current in the positive sequence network is made of two parts: the pre-fault current and the change in current caused by the fault. The former quantity must be subtracted from the oscillogram to find the change. Upon opening of the fault path by the protector tube again we know that the changes in the positive and negative sequence networks will be the same since the changes due to the opening may be found by locating a current source across the terminals of the switch at the instant corresponding to the opening. Thus here again to find the changes we must subtract the values which would have existed if no opening had occurred from the oscillograms of both positive and negative sequence quantities.

Another trouble encountered with symmetrical components is that corresponding to the time of circuit opening in the three-phase circuit, the switches in the sequence network must open when they are carrying a finite current. The difference in zero current-time relationships is again brought about by the complex operators. As an example, consider a line to line fault between phases b and c. Let the opening be caused by a circuit breaker. The breaker will open when $i_b = 0$ and for simplicity assume that all transient terms have died out at the time of

[5] I_0, I_1, and I_2 stand for the symmetrical components of the three line currents I_a, I_b, and I_c.

opening and that the magnitude of the fault current is $|I_b|$. Then the sequence currents are at the time of opening

$$\begin{aligned} i_0 &= 0, \\ i_1 &= |I_b| \sqrt{3} \sin 90°, \\ i_2 &= -|I_b| \sqrt{3} \sin 90°. \end{aligned} \tag{7}$$

Thus at the time at which the switch should open the positive and negative sequence currents are finite. A clean opening cannot be accomplished as this involves instantaneous changes of magnetic and electric field energies. Any opening attempted will produce sparking and will destroy the true transient picture, and certainly any forced opening is not in agreement with the opening conditions. Generally speaking, whenever an opening in the sequence networks is required, and phase *b* and *c* currents are involved in the determination of positive and negative sequence currents, then the opening cannot be accomplished physically if the switches are in either of these sequence networks.

In the study of simultaneous or changing faults in transient studies very often a phase-shifting transformer must be introduced in the sequence networks if the faults are not symmetrical with respect to phase *a*. These transformers are impractical. As an example of a changing fault consider a double line to ground fault occurring on phases *b*, *c*, and ground. Suppose an opening occurs in the path from *c* to ground. Then the result is a line to ground fault on phase *b* and this sequence equivalent requires such a transformer. The same difficulty occurs in the analysis of shunt faults and a following series opening by a circuit breaker.

These arguments furnish the proof that symmetrical components cannot be used generally in transient studies on a network calculator. The only practical exception occurs for a fault involving one phase only, but even here a direct method cannot be used. It should be realized that all these difficulties arise only when a calculating board is used in the solution of the transient problem; in an analytical solution, these difficulties have no importance. Since the analytical solution of even fairly simple problems may become rather cumbersome, transient analyzers (13) or analog computers (24) have been used instead in the last few years to a large extent. It is important to investigate means which would bring simplifications and single-phase representation may be a time saving improvement.

Even though symmetrical components are not applicable in transient studies, it should not be thought that no method of single-phase solution of three-phase networks is available. A transformation involving only real numbers in the transformation matrix eliminates all the difficulties arising in symmetrical components. Such a transformation has been used extensively (2) by Edith Clarke and her associates, and the name

Clarke components (25) has been suggested for her alpha, beta, zero-components (2). It will be shown in Part II of this paper that Clarke components serve well in transient analysis and provide single phase equivalent circuits for the various types of transient disturbances.

CONCLUSIONS

1. Transient phenomena occurring on three phase power systems have been investigated in the last decade on network calculating boards by studying a three-phase replica in miniature with the help of oscilloscope and synchronous switch.

2. It would be desirable to use a single-phase representation of the three-phase system for the study of transient phenomena.

3. Symmetrical components so widely used in steady state analysis of power systems are found wanting as a means of representation of the problem. However, their usefulness halts at steady state analysis. The complex numbers in the transformation of symmetrical components are the roots of the difficulties encountered.

4. It will be shown in Part II of the paper that Clarke components serve well in transient analysis, are often simpler and require less impedance elements than representation by a miniature three-phase system.

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APPENDIX. PROOF OF THE INSUFFICIENCY OF DATA IN A SYMMETRICAL COMPONENT ANALYSIS OF A TRANSIENT PROBLEM

This proof will show that the quantity desired in a symmetrical component analysis cannot be found from the quantity given. For simplicity let

$$B_m F_m(t) \sin (k_m t + \zeta_m) = C_m(t). \tag{8}$$

Considering only the transient terms, we have identically,

$$\sum_{m=1}^{n} C_m(t) \sin \theta_m = \sum_{m=1}^{n} C'_m(t) \sin \theta'_m,$$

where

$$C'_m(t) = r_m C_m(t)$$

$$\sin \theta'_m = \frac{\sin \theta_m}{r_m} \tag{9}$$

for which the n quantities r_m may be chosen in an arbitrary manner consistent with the restriction that r_m be greater than 1. The oscillogram may be either of these expressions since we have insufficient data to

determine which it is. It is obvious that for any term

$$\sin(\theta'_m + 120°) = \frac{\sin(\theta_m + 120°)}{r_m} + \frac{\sqrt{3}}{2}\frac{\sin(\theta_m - \theta'_m)}{\sin\theta_m} \tag{10}$$

so that generally

$$\sin(\theta'_m + 120°) \neq \frac{\sin(\theta_m + 120°)}{r_m}. \tag{11}$$

Thus it is always possible to choose the n quantities r_m so that

$$\sum_{m=1}^{n} C_m(t)\sin(\theta_m + 120°) \neq \sum_{m=1}^{n} C'_m(t)\sin(\theta'_m + 120°). \tag{12}$$

Thus beginning with two identically equal series in which the functions $C_m(t)$ and the arguments θ_m are unknown, an arbitrary increase of the argument of the sine function does not result in a unique solution because the lack of definite knowledge of these quantities permits the fluctuation of the arbitrary multipliers r_m.

We are indebted to our colleague, professor Michael A. Sadowsky, for advice and assistance rendered in this proof.

New Box Board from Straw.—A box board from straw, to replace critical wood veneer now used in making wire-bound shipping containers for farm and industrial products, was reported at the annual meeting of the Technical Association of the Pulp and Paper Industry.

This new product is the result of research by the U. S. Department of Agriculture's Bureau of Agricultural and Industrial Chemistry in cooperation with industry. The straw box board was developed by Drs. E. C. Lathrop and T. R. Naffziger of the Bureau's Northern Regional Research Laboratory at Peoria, Ill., working with engineers of the Stapling Machines Company of Rockaway, N. J., who designed, fabricated, and tested boxes made with the board.

Straw box board is important, the report states, because of increasing demands for wood veneer, or thin lumber, in uses other than box making. Manufacturers of wire-bound boxes may have difficulty, the pulp and paper men were told, in getting enough wood to meet requirements for low-cost shipping containers.

The straw box board could replace much of the 1.5 billion square feet of wood veneer needed annually for wire-bound boxes. At the same time, according to the report, it could provide a use for some 500,000 tons of straw, which is readily available as part of the country's annual straw surplus, totaling about 40 million tons.

An outstanding advantage of the new board-making process, is that it uses standard equipment already employed by or available to the insulating building board industry. The thickness of the straw box board can easily be varied from a sixth to a quarter inch, depending on the type of box needed for specific uses.

Straw box board does not possess all the physical properties of wood, but tests show that its performance in wire-bound boxes is equally satisfactory. Standard wire-bound boxes made of the new board, containing loads of 100 to 200 pounds, withstood both drop and rough-handling tests as well as boxes made from like thicknesses of wood veneer.

One obstacle the engineers met and overcame was that, although the wires do not cut into wood veneer in a box, they did cut into the straw box board. This problem was solved by putting a metal edging on the board, similar to the edging often used on paper pie plates.

Both industrial products and fruits and vegetables are shipped in wirebound containers, the report points out. Many agricultural products originate in the South, where veneer mills are near and straw is scarce. The North, on the other hand, has few veneer mills but ample supplies of straw. Therefore, first consideration in the new development has been given to relieving the shortage of wood-veneer shipping containers for the North's industrial products.

Interest in the production of box board from straw, has resulted in several straw surveys by State agencies in the Middle West. They show that straw is surplus to farm needs in some areas, which can produce a reliable supply of straw, and where gas, water, electricity, labor, and means for waste disposal are ample. Such areas are ideal for straw-board manufacture. Cost estimates on the basis of a plant producing 123 tons of straw box board per day indicate that the board can be manufactured at a price competitive with wood veneer and attractive to box makers.

FREQUENCY-COORDINATE VECTOR DIAGRAM

BY

PHILIP F. ORDUNG [1] AND HERBERT L. KRAUSS [1]

SYNOPSIS

From the standpoint of circuit synthesis as well as for a fundamental comprehension of circuit behavior, it is desirable to be able to visualize the response of a circuit over an extended frequency range by means of a geometrical construction. Mathematically, the response of a circuit can be expressed with the La Place transform theory as a function of the complex frequency variable, $p = \alpha + j\omega$, in which α is the decrement and ω is the "real" angular frequency. Physically, the nature of the real-frequency response is usually not discernible by casual inspection of the mathematical function. This paper develops a means of visualizing this frequency response readily through the construction of a vector diagram from the response function.

INTRODUCTION

The frequency-coordinate vector diagram will be developed through a straightforward analysis of the two-mesh circuit shown in Fig. 1. In the manner of conventional circuit analysis, the mesh currents that flow in the network in response to the impressed voltage are readily expressed as

$$I_1 = \frac{\Delta_{11}}{\Delta} E_1 e^{pt}$$

$$I_2 = \frac{\Delta_{12}}{\Delta} E_1 e^{pt} \tag{1}$$

in which Δ is the determinant of the contour impedances of network and Δ_{11} and Δ_{12} are two of its cofactors. For the network of Fig. 1,

$$\Delta = \begin{vmatrix} Z_{11}(p) & Z_{12}(p) \\ Z_{21}(p) & Z_{22}(p) \end{vmatrix} = Z_{11}(p)\, Z_{22}(p) - [Z_{12}(p)]^2, \tag{2}$$

$$\Delta_{11} = Z_{22}(p),$$

$$\Delta_{12} = -Z_{21}(p).$$

The contour impedances in (2) are determined directly from the network in the customary manner as

$$Z_{11}(p) = R_1 + R_2 + L_1 p + \frac{1}{C_1 p} = 20 + 10^{-3} p + \frac{10^6}{p},$$

$$Z_{12}(p) = Z_{21}(p) = -R_2 - \frac{1}{C_1 p} = -10 - \frac{10^6}{p},$$

$$Z_{22}(p) = R_2 + L_2 p + \frac{1}{C_1 p} = 10^{-3} p + \frac{10^6}{p}. \tag{3}$$

[1] Dunham Laboratory, Yale University, New Haven, Conn.

When the determinants in (1) are evaluated as follows

$$\Delta = 10^{-6}p^2 + 0.03p + 2.1 \times 10^3 + \frac{10^7}{p}$$

$$\Delta_{11} = 10^{-3}p + 10 + \frac{10^6}{p}$$

$$\Delta_{12} = \Delta_{21} = -10 - \frac{10^6}{p}$$

$$\Delta_{22} = 10^{-3}p + 20 + \frac{10^6}{p} \tag{4}$$

the currents in the network as expressed in (1) may be written as

$$I_1 = E_1\left[\frac{10^{-3}p + 10 + \frac{10^6}{p}}{10^{-6}p^2 + 0.03p + 2.1 \times 10^{-3} + \frac{10^7}{p}}\right],$$

$$I_2 = E_1\left[\frac{10 + \frac{10^6}{p}}{10^{-6}p^2 + 0.03p + 2.1 \times 10^{-3} + \frac{10^7}{p}}\right]. \tag{5}$$

By multiplying the numerator and the denominator through by p and factoring, the expressions for the currents in (5) may be rewritten as

$$I_1 = 10^3E_1\left[\frac{(p+5\times10^3+j3.12\times10^4)(p+5\times10^3-j3.12\times10^4)}{(p + 5.06 \times 10^3)(p + 1.247 \times 10^4 + j4.26 \times 10^4) \times (p + 1.247 \times 10^4 - j4.26 \times 10^4)}\right],$$

$$I_2 = 10^7E_1\left[\frac{p + 10^5}{(p + 5.06 \times 10^3)(p + 1.247 \times 10^4 + j4.26 \times 10^4) \times (p + 1.247 \times 10^4 - j4.26 \times 10^4)}\right]. \tag{6}$$

By substituting $j\omega$ for p, the expressions in (6) yield the steady-state values of the currents as a function of frequency. From the manner of derivation of these equations, it is clear that for a network of n meshes a similar procedure would be followed to obtain the mesh currents. The resulting equations would contain more factors but would have the same general form, that is,

$$I = E \cdot K\left[\frac{(p + a_1)(p + a_2)\ldots(p + a_m)}{(p + b_1)(p + b_2)\ldots(p + b_n)}\right], \tag{7}$$

where K is a constant.

FREQUENCY-COORDINATE VECTOR DIAGRAM

Since the complex frequency p is a function of two independent variables, α and $j\omega$, it may be plotted as a point in a complex-frequency plane (also called the p-plane) having α and ω as the coordinate axes as shown in Fig. 2. The roots $(-a_m, -b_n)$ of the numerator and denominator of Eq. 7 may be plotted as points in this complex-frequency plane.

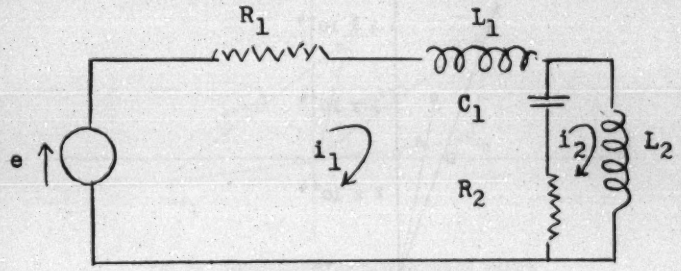

FIG. 1. Circuit used for a sample calculation.

$R_1 = R_2 = 10$ ohms
$C_1 = 1\mu f$
$L_1 = L_2 = 1mh$

The roots of the numerator $(-a_1, -a_2, \ldots -a_m)$ are termed the "zeros" of the network admittance function, because the value of the response to E volts is zero when the complex frequency p has the value of one of these roots. The zeros are customarily indicated by circles drawn at the respective points on the p-plane. When p has values corresponding to the roots $(-b_1, -b_2, \ldots -b_n)$ of the denominator of (7) the magnitude of the response is infinite and these points are called "poles" of the network admittance function. The poles are indicated by crosses on the p-plane. The zeros and poles of I_1 are shown in Fig. 2.

The steady-state response of the network to a sinusoidal driving voltage having a particular frequency can be computed, except for the constant multiplier, by a vector diagram drawn on the complex frequency plane. A frequency p is represented in Fig. 3 by a vector drawn from the origin to the point p. Similarly, a factor such as $(p + a_1)$ in (7) may be represented by a vector drawn from the origin to the point $(p + a_1)$; however, it is usually more convenient to represent this vector as drawn from the root $(-a_1)$ to p as is shown in Fig. 3. Obviously, each of the factors within the brackets of (7) may be represented by a vector drawn from the respective root to the given frequency p. The value of the expression within the brackets is then the product of the vectors representing the numerator (zeros) divided by the product of the vectors representing the denominator (poles). By plotting each vector

accurately and measuring its length and the angle that it makes with the positive α-axis, one may evaluate (7) by standard vector methods; that is, by obtaining the magnitude of (7) as the ratio of the product of the magnitudes in the numerator to the product of the magnitudes in the

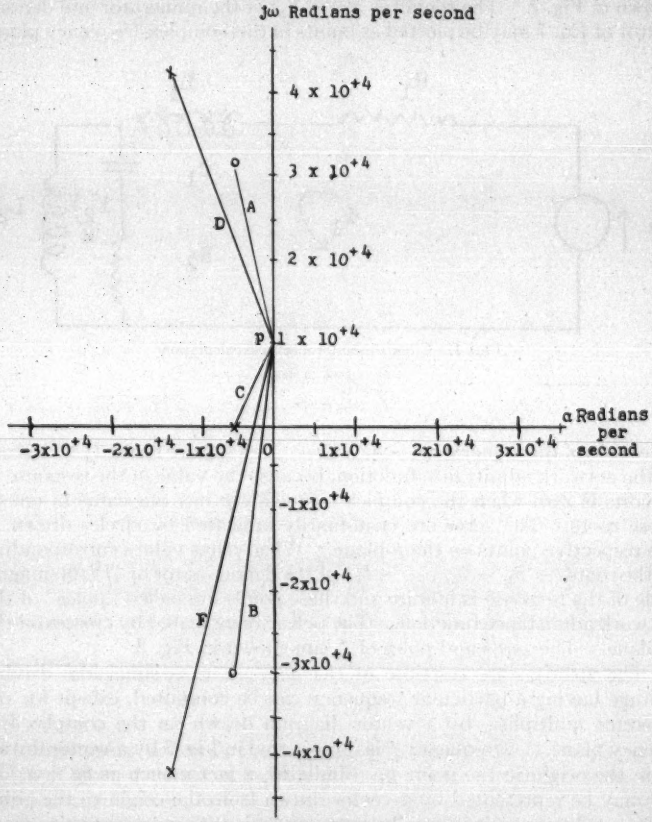

FIG. 2. Frequency coordinate vector diagram for the driving point admittance of the network shown in Fig. 1. It is drawn for an impressed voltage having a frequency $p = j10^4$ radians per second.

denominator, and by obtaining the total phase angle as the sum of the numerator angles minus the sum of the denominator angles.

Figure 2 illustrates a computation of this sort for the current I_1 in the network of Fig. 1, when it is driven by a sinusoidal voltage of frequency

$p = j10^4$. Vectors are drawn to the point $p = j10^4$ from each of the zeros and poles in the Eq. 6 for I_1. For example, vector A represents the factor $(p + 5 \times 10^3 - j3.12 \times 10^4)$. The measured magnitudes

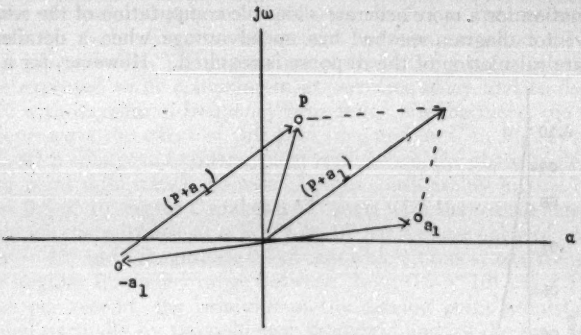

FIG. 3. Representation complex factors by vectors.

and angles from the diagram for the vectors A to F are:

$$A = 2.15 \times 10^4 \angle -77.0°$$
$$B = 4.10 \times 10^4 \angle 83.0°$$
$$C = 1.15 \times 10^4 \angle 62.0°$$
$$D = 3.50 \times 10^4 \angle -69.5°$$
$$F = 5.40 \times 10^4 \angle 77.0° \quad .$$

Thus, for E_1 volts applied at the frequency $p = j10^4$,

$$I_1 = 10^3 E_1 \left[\frac{A \angle \theta_A \cdot B \angle \theta_B}{C \angle \theta_C \cdot D \angle \theta_D \cdot F \angle \theta_F} \right]$$

$$= 10^3 E_1 \left[\frac{2.15 \times 10^4 \times 4.10 \times 10^4 \angle -77.0 + 83.0}{1.15 \times 10^4 \times 3.50 \times 10^4 \times 5.40 \times 10^4 \angle 62.0 - 69.5 + 77.0} \right] \tag{8}$$

$$= 0.041\, E_1 \angle -63.5°.$$

The factor 10^3 that appears in the above is the constant multiplier in (6) and it cannot be represented on the vector diagram of Fig. 2. In this manner the driving-point admittance of the network (the current that flows into the input terminals when one volt is impressed) over the entire frequency range from zero to infinity can be investigated with ease. Likewise this procedure applies to I_2; hence, the transfer admittance from the driving terminals to mesh two can also be investigated easily

over the entire spectrum. Obviously this same procedure applies to more general network functions involving many more poles or zeros.

At this point the reader may wonder why a graphical method should be used for these calculations, when Eq. 6 contains all the necessary information for a more accurate slide-rule computation of the response. The vector diagram method has no advantage when a detailed and accurate calculation of the response is required. However, for a quick

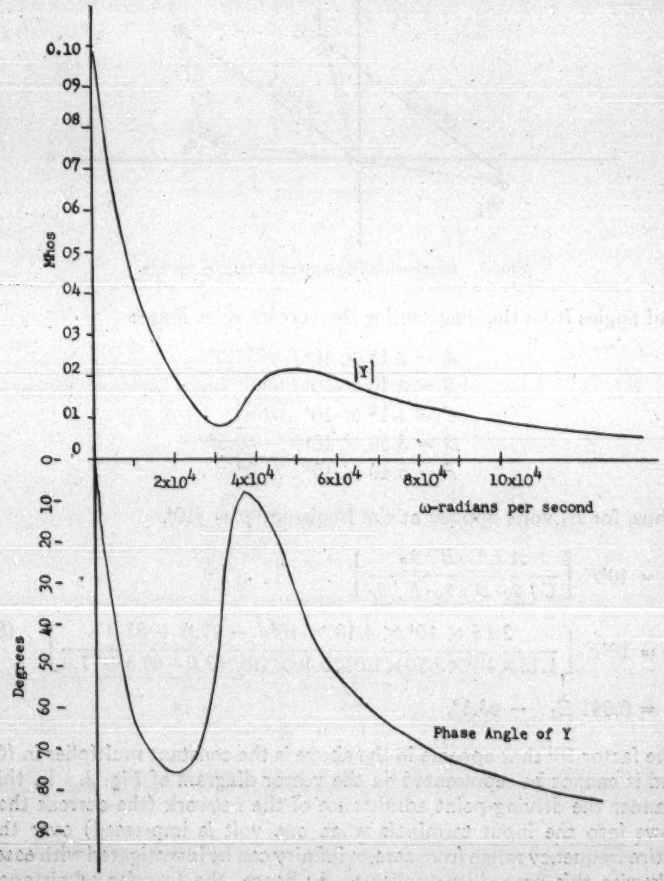

FIG. 4. The phase and magnitude of the driving point admittance of the network shown in Fig. 1 as a function of ω.

estimate of the probable magnitude and phase response as a function of frequency, the geometrical presentation of the problem may be of great value because the location of the zeros and poles with respect to each other and to the ω-axis determine the nature of the response. For example, the isolated pole near the origin in I_1 has the predominant influence on I_1 for angular frequencies between zero and 0.5×10^4 radians per second. The magnitude of the driving point admittance can be expected to be a maximum at zero frequency and to decrease rapidly with increase of frequency near zero. Furthermore, the vector that represents the effect of this pole (denoted as C in Fig. 2) rotates rapidly with change in frequency near zero; hence, the phase angle of the driving point admittance likewise changes considerably in this region. At $\omega = 0.5 \times 10^4$ vector C makes a 45° angle with the α axis; hence, the driving point admittance at $\omega = 0.5 \times 10^4$ has a phase angle of approximately $-$ 45° and a magnitude 0.7 of that which it has at zero frequency. In the angular frequency range between about 0.5×10^4 and 2.5×10^4 radians per second, the behavior of the driving point admittance is governed mutually by the pole near the origin and by the zero and the pole in the upper quadrant; the pole and the zero in the lower quadrant approximately cancel each other. The driving point admittance can, therefore, be expected to have relatively gradual variation with respect to frequency in this range. Its magnitude will decrease gradually with increase in frequency, and its phase angle will remain relatively constant until the frequency enters the range between 2.5×10^4 and 3.5×10^4 radians per second where the nearby zero, which has the vector A, has the predominant influence. The change in phase angle of the admittance as ω goes from 2.5×10^4 to 3.5×10^4 radians per second is approximately 90°. Somewhere near the center of this range the driving point admittance has a minimum. The magnitude of the admittance at 2.5×10^4 and 3.5×10^4 radians per second is approximately 1.4 times its magnitude at the minimum. In the range beyond that of the predominant influence of this zero, the pole in Fig. 2 that has vector D can be expected to have an effect; however, its effect is not so dominant as that of the other zeros and poles because it is further removed from the $j\omega$ axis than the other zeros and poles and because it is in the vicinity of a zero that is closer to the $j\omega$ axis than itself. This pole and its neighboring zero can be expected to produce a maximum in the driving point admittance at an angular frequency slightly greater than $\omega = 4 \times 10^4$ radians per second. Beyond this maximum the magnitude of the driving point admittance approaches zero monotonically due to one more pole than zero and the phase angle will approach $-$ 90° at infinity.

The exact behavior of the driving point admittance of the network of Fig. 1 is shown in Fig. 4. It should be noted that the behavior predicted from the foregoing discussion is verified in Fig. 4.

CONCLUSIONS

The frequency-coordinate vector diagram enables a designer to visualize the frequency behavior of a network function in terms of a geometric picture. In simple networks such as the low-pass filter, the parallel-resonant, and the series-resonant circuit, the behavior of the magnitude and phase angle of the impedance are easily visualized in terms of the vectors on the vector diagram. This same method of visualization is useful in connection with hosts of other circuits; for example, the attenuation outside of the pass band of an ordinary filter can be readily observed on such a diagram as a function of the critical frequencies of the filter.

In general the results indicate that the magnitude of the function being investigated will have its maxima and minima and its most rapid changes in phase angle in the vicinity of the poles and zeros. Also, poles and zeros will have a greater effect as they are brought closer to the ω-axis. The general problem of synthesizing a network to provide a specified response function is one of locating the zeros and poles properly, and then finding the circuit that will produce them. Moreover, the mathematical connections between attenuation and phase shift for four terminal structures or between resistance and reactance for two terminal structures are given pictorial significance by the frequency-coordinate vector diagram.

ELECTRON DIFFRACTION STUDIES OF ETCHED AU LEAF FILMS

BY

W. V. STAUDER[1] AND A. H. WEBER[1]

ABSTRACT

Anomalies occurring in electron diffraction patterns of etched Au leaf films were studied. The anomalies were of two kinds, extra lines and orientation effects. The extra lines, in agreement with the report of Thomson and Cochrane, were attributed to contamination of the films by some long chain compound. The orientation effects consisted of a variation of the intensities of several of the lines of the Au patterns obtained from the intensity of these same lines as observed in standard patterns of randomly-oriented Au. These abnormal intensities evidenced the existence of the [100] crystal direction as an axis of orientation perpendicular to the face of the film. A second orientation effect, the arcing of some of the lines of the Au patterns, indicated a second axis of orientation parallel to the face of the film but insufficient evidence prevented the identification of this axis of orientation. Results of the orientation study confirm the findings of other investigators, particularly those of Trillat and Hirsch.

During a series of experiments on electron diffraction in thin Bi films (1)[2] Au leaf was employed to obtain a standard reference pattern. The etched Au leaf patterns obtained by the transmission method exhibited certain anomalies which were studied in some detail and are here reported. Although these anomalies are not new they have been reported in rather brief and fragmentary fashion by many workers. Hence it was considered worthwhile to report the present findings in fairly complete form. The anomalies noted are of two kinds—"extra" rings and orientation effects. Conclusions regarding the "extra" rings conform to the observations of Thomson and Cochrane (2), while the interpretation of the orientation effects confirms the findings of a somewhat similar study by Trillat and Hirsch (3) (in French).

EXPERIMENTAL

The electron diffraction camera used in this investigation is substantially the same as that used by Keogh (1). The essential design follows that of the electrostatic focusing camera described by Ruedy (4), while the photographic recording unit (5) and the electron gun structure (1) have been designed to fit the needs of this laboratory. The latest improvements, intended to shield the electron beam from varying magnetic fields in the vicinity of the camera, include complete shielding of the electron beam by means of mu-metal sleeves fitting

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

snugly over the second anode and inside the main (third anode) cylinder of the diffraction camera, and orientation of the axis of the diffraction camera so as to coincide with the direction of the local total magnetic field. Regulated power supplies provide the voltage for the first and second anodes. The accelerating potential of the third anode is of

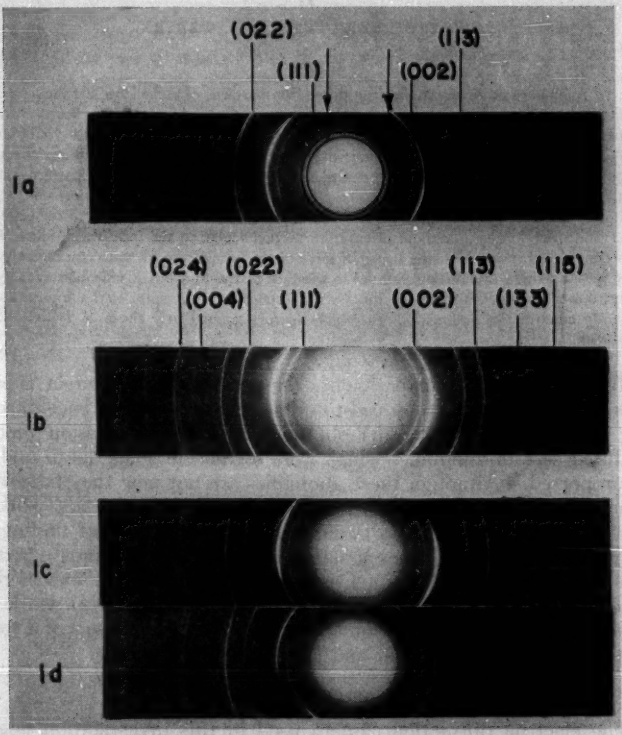

FIG. 1. Transmission electron diffraction patterns of etched Au leafs.

Numbers in parentheses are Miller indices. 1a, electron beam perpendicular to Au specimen, extra inner rings appearing (indicated by arrows and retouched with India ink to bring them out clearly in reproduction); 1b, electron beam perpendicular to Au specimen, inner rings absent; 1c, 1d, electron beam respectively perpendicular and at an incidence angle of 60° approximately to the same Au specimen.

the order of 33 Kv and is supplied from a full wave rectifier with capacitor (0.25μf) filtering.

The Au films employed in the experiments were prepared from commercial gold leaf obtained from the Central Scientific Instrument Company, Chicago, Illinois. The gold leaf was etched to suitable

thickness for electron diffraction work by floating a small foil on a dilute solution of aqua regia. The final thickness of the film was of the order of 100 A.

The experiments with Au films were of two kinds. First, several diffraction patterns were obtained with the electron beam perpendicular (as visually determined) to the film. As these patterns showed anomalies in the form of arcing of some of the lines and of an alteration of the relative intensities of the several lines of the patterns as compared to the intensities of these same lines observed in published standard powder X-ray and electron diffraction photographs of Au, a second series of patterns was obtained in which the specimen was rotated about an axis perpendicular to the electron beam, thereby establishing an angle different from 90° between the incident electron beam and the plane of the specimen. Diffraction patterns were obtained at angles of inclination of the plane of the film to the electron beam of approximately 60°, 70°, 80° and 90°.

RESULTS

A typical electron diffraction pattern of the Au foil for perpendicular incidence of electrons appears in Fig. 1(*a*). The experimentally determined characteristics of the pattern appear in Table I. The X-ray

TABLE I.—*Data for the Au Specimen of Fig. 1(a).*

R, Radii of the Diffraction Rings, cm.	Miller Indices Face-Centered Cubic, *hkl*	Calculated d_{hkl}, A	Hanawalt d_{hkl}, A
0.6793	——	4.14	——
0.7551	——	3.73	——
1.1979	(111)	2.35	2.35
1.3887	(002)	2.03	2.03
1.9602	(022)	1.437	1.439
2.2988	(113)	1.225	1.227
3.0261	(133)	0.930	0.935
3.1047	(024)	0.907	0.910
3.6059	(115, 333)	0.781	0.784

values of Hanawalt, Rinn, and Frevel (6) for d_{hkl} are also listed in the table for purposes of comparison.

From examination of Table I and the accompanying diffraction pattern Fig. 1(*a*), it may be seen that all diffraction rings observable are indentified as Au lines except the two inner lines marked with arrowheads. These lines are fairly strong and quite sharp. They had *d* values of 4.14 and 3.73 A. They do not correspond to any lines found in a usual Au pattern nor are they identifiable by reference to the Hanawalt X-ray tables. These two lines first appeared only after an attempt at deposition of Bi on Formvar substrates at low temperatures in the diffraction camera, the Formvar substrates being mounted on the same specimen holder as the Au films. The pattern shown in

Fig. 1(*a*) was taken the day following the attempted deposition of Bi, the specimen having remained at the room temperature for approximately twenty-four hours. The two inner lines gradually disappeared over a period of days. Hence the extra lines are due probably to some impurity which condensed on the Au film at low temperatures. The same two lines, or traces of them, have been observed on several other patterns obtained both from Au and other substances.[3]

Thomson and Cochrane explain such extra lines as caused by the contamination of thin films by long chain molecules such as paraffin or wax. In general, extra rings are frequently encountered by investigators in electron diffraction. "The strongest spacings observed are at about 4.14, 3.67, 2.92, and 2.50 A" (2). The correspondence between the first two of these rings and those observed in this study and the identification of *d* values of extra rings of another pattern not shown here of 4.12, 3.65, 2.95, 2.50, and 2.22 A are definite evidence that the rings presently observed are the same as those referred to by Thomson and Cochrane.

In addition to the Au diffraction pattern shown by Fig. 1(*a*), other Au patterns are shown by Figs. 1(*b*), 1(*c*), and 1(*d*). Figure 1(*b*) shows more diffraction rings than Fig. 1(*a*) but the inner rings are absent because some time (several days) has elapsed since the corresponding Au specimen was at a low temperature. Figures 1(*c*) and 1(*d*) show the effect of rotating the specimen about an axis perpendicular to the electron beam. Figure 1(*c*) was obtained at perpendicular incidence of the electron beam on the Au film; Fig. 1(*d*) was obtained for the same film at an angle of incidence of approximately 60°.

Upon examination of the patterns of Fig. 1, and by comparison with an electron diffraction pattern of randomly-orientated Au it can be verified that the relative intensities of several of the Au lines in the patterns of Fig. 1 differ markedly from those observed in a normal Au pattern. Although X-ray and electron diffraction intensities are calculated differently, there is a functional relationship between the two, and so the relative intensities from the Hanawalt X-ray tables can be used to measure qualitatively any discrepancies of the intensities of the lines of the patterns shown here from those of a powder pattern of randomly-oriented material.[4] The intensities of the lines observed visually in Figs. 1(*a*) and 1(*b*) and the relative intensities of a powder pattern of randomly-oriented material as found in the Hanawalt X-ray tables are arranged in Table II. It is noted that in Table II the measures of the intensity of the various lines of Figs. 1(*a*) and 1(*b*) differ

[3] J. Antal, in work just completed in the St. Louis University Laboratories, found these same lines on Bi films evaporated onto Formvar in vacuum. The lines seem to be most dominant at a temperature of about −12° C. Cf. Thesis, St. Louis University, 1949.

[4] A comparison between the intensities of Au lines in the Hanawalt charts and the relative intensities of a randomly-oriented electron diffraction Au powder pattern justifies this argument.

considerably from the relative X-ray intensities I/I_1 of Hanawalt. The (002), (022), (004), and (024) lines in particular are stronger than in a normal pattern. These are lines from reflection planes of the type (*Okl*). These intensity anomalies represent the first kind of orientation effect observed in the present Au patterns obtained from etched Au leaf films.

A second orientation effect is found in the arcing of several of the rings of the patterns. This arcing is especially noticeable for the same lines which were noted in the preceding paragraph as being abnormally intense. As the specimen is rotated about an axis perpendicular to the electron beam, the position and sometimes the symmetry of these arcs changes as may be observed in Figs. 1(*c*) and 1(*d*).

Orientation effects are discussed usually in terms of a preferential orientation of a crystal direction (for example the [111] direction). In thin films it is found that the crystal direction (or orientation axis) may be oriented in the plane of the film, perpendicular to the plane of the film or (in more complex forms) both in and perpendicular to the plane of the film.

TABLE II.—*Comparison of Intensities* for Figs. 1(a), 1(b).*

Line	d_{AH}	Fig. 1(*a*)	Fig. 1(*b*)	Hanawalt I/I_1
(111)	2.35	M	M	1.00 VS
(002)	2.03	VS	VS	.53 M+
(022)	1.439	M+	M+	.33 M−
(113)	1.227	M−	M−	.40 M
(004)	1.019		W	.03 VW
(133)	0.935	M−	M−	.09 W
(024)	0.910	M	M	.07 W
(224)	0.832		VW	.04 VW
(115, 333)	0.784	W	M−	.04 VW

* Intensities are graded in order as follows: VS, S, M+, M, M−, W, VW.

In electron diffraction transmission patterns orientation of crystal directions perpendicular to the plane of the film is readily detected. Consider the electron beam as striking the plane of the film at perpendicular incidence. The axis of orientation is then parallel to the electron beam. Only those families of Bragg planes, depending on the degree of orientation, will reflect which are parallel or nearly so (Bragg angles for electron diffraction are usually of the order of one degree or so) both to the electron beam and to the axis of orientation. The resulting diffraction pattern will consist of rings of fairly uniform intensity (that is, no arcing), but considerably increased relative to the intensities of a normal (random orientation) pattern. If the electron beam strikes the film at any other than perpendicular incidence, the variation of intensity will be accompanied by arcing since for non-perpendicular incidence a few only of the planes of the oriented crystallites are parallel to the incident beam.

Orientation of a crystal direction parallel to the plane of the film, on the other hand, always manifests itself by arcing. In more complex cases where both kinds of orientation are present (parallel and perpendicular to the plane of the film) both arcing and a change in the relative intensities of the diffraction lines will occur.

Interpreted in the light of the above two paragraphs, the patterns of Fig. 1 obviously manifest a crystal direction oriented perpendicular to the plane of the film. Several lines of the patterns are of abnormal intensity. The change in intensity gives way to arcing (Figs. 1(*c*), 1(*d*) as the electron beam deviates from perpendicular incidence upon the Au film.

But the arcing of some of the lines in addition to greater uniform intensity even before inclination of the film is more difficult to interpret (Figs. 1(*a*), 1(*b*). This arcing may be caused by slight variations from perpendicular incidence of the electron beam to the plane of the film. It may also be caused by a second axis of orientation parallel to the plane of the film. The patterns yield insufficient data to determine an unambiguous interpretation.[5]

TABLE III.—*Planes of the Cubic System Inclined at Less than 20° to the [100] Direction.**

$h^2+k^2+l^2$	(*hkl*)	α	$\theta(\lambda=.06A)$
4	(002)	0°	51′
8	(022)	0°	1° 12′
11	(113)	17° 30′	1° 24′
16	(004)	0°	1° 43′
19	(133)	13° 30′	1° 51′
20	(024)	0°	1° 54′
27	(115)	11°	2° 12′
32	(044)	0°	2° 24′

*Taken from Trillat and Hirsch, ref. 3.

The axis of orientation parallel to the electron beam can be identified. It was shown above that planes parallel or nearly parallel to an axis of orientation which in turn is parallel to the electron beam will result in the more intense lines of the diffraction pattern. The lines of the patterns noticeably increased in intensity have been pointed out from Table II as corresponding to families of Bragg planes of the type (*Okl*). Such planes are all parallel to a cube edge. Therefore, a cube edge must be the axis of orientation, or the axis of orientation perpendicular to the plane of the Au film is the [100] axis.

Since the [100] axis is an axis of orientation perpendicular to the plane of the specimen, planes making small angles with this axis will

[5] Had large patterns showing entire rings been obtained instead of portions only of the arcs, the presence or absence of a second axis of orientation could have been determined, for there is a relation between the symmetrical arrangement of the arcs on a given ring and the angle the planes corresponding to that ring make with the axis of orientation. Cf. Charles S. Barrett, "Structure of Metals," New York, McGraw-Hill Book Co., 1943, pp. 154–158.

also reflect. For the cubic system the angle α at which a plane is inclined to this axis is given by (3)

$$\tan\alpha = h/(k^2+l^2)^{\frac{1}{2}}. \qquad (1)$$

Families of planes for which α is small are of the type (unity, kl). Allowing for imperfection of orientation, planes having α as large as 20° should reflect. These planes are listed in Table III.

Reflections from all the planes of Table III are observable in the patterns of Figs. 1(*a*) and 1(*b*) and in every case the intensity is greater than normal. The reflections from the (111) planes, on the other hand, for which $\alpha = 35°$, have their intensity decreased by a factor of two or three thus verifying the identification of the [100] axis as the axis of orientation perpendicular to the plane of the film.

The conclusions stated above are in agreement with the findings of Trillat and Hirsch (3) and of G. P. Thomson (7). Trillat and Hirsch further conclude that their patterns are effected by diffraction of the electron beam by single Au crystals whose planes have been considerably warped by the process of hammering employed in the formation of the Au leaf film.

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The Tinsley Single Unit Pen Recording Polarograph (*Instrument Practice*, Vol. 5, No. 2).—Polarography is a rapid and accurate technique of chemical analysis in which the electrolysis of solutions between a dropping mercury cathode and a mercury pool anode is studied. During the electrolysis, a voltage which increases at a uniform rate is applied to the cell and the current/voltage curves thus obtained are recorded.

From a study of these curves, which are known as polarograms, the character and concentration of the substances in solution can be determined. The concentration is found from the current increase, or the step height as it is called. The nature of the substance is indicated by the voltage at which the corresponding step occurs.

The technique is essentially a simple one and does not involve the use of complicated apparatus. The Tinsley Polarograph can be used by semi-skilled staff.

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A glass fiber filter paper developed by Naval Research Laboratory is 5000 times more effective than present commercially available filters, contains no foreign imports. Made of glass fibers 1/20th the thickness of a human hair, the paper is impervious to fungus, can be manufactured by any paper mill in the United States with a minimum of instruction. During National Bureau of Standards test runs, the paper was produced in 1/100th inch thickness at 28 feet per minute; full scale mill runs have also been made. Thinner and capable of withstanding more intense heat than insulating papers now used in condensers, it will make for reduction in size of condensers used in electronic equipment; added industrial and military uses expected because of its electrical insulating properties.

MACROSCOPIC SENSITOMETRY, OPACITY AND PHOTOGRAPHIC DENSITY, SPECULAR AND DIFFUSE

THE QUANTIC EXPOSURE LAW (DENSITY AS FUNCTION OF EXPOSURE) FOR A UNIFORM EMULSION. EMULSIONS CONTAINING SILVER HALIDE GRAINS OF DIFFERENT SIZES. GENERAL FORMULAE AND THEIR APPLICATION TO EMULSIONS OF EXPONENTIAL AND GAUSSIAN OR "NORMAL" SIZE-FREQUENCY DISTRIBUTION OF GRAINS. SOME RELATIONS VALID FOR ANY SIZE-FREQUENCY DISTRIBUTION

BY

LUDWIK SILBERSTEIN [1]

In the proper field of the art of photography and its practical applications, it is not the number and size of the individual grains made developable by an exposure which are required, but the macroscopic, summary effect of the presence of such grains, the opacity of the film or plate over which the developable and, ultimately, the developed grains, embedded in gelatin, are spread; in fine, the cumulative effect of such grains in blotting out some fraction of the incident radiation.

If I_0 be the intensity of the light incident upon and penetrating into a film,[2] and I the intensity of the transmitted light, the *transparency*, or "transmission" of the film is defined as the ratio

$$T = I : I_0$$

so that its range is $T = 0$ to 1. The *opacity* of the film (or plate) is the reciprocal of the transparency, its range is 0 to ∞. What the student of photography calls *density* is the common or Briggian logarithm of the opacity

$$D = \log \frac{1}{T} = \log \frac{I_0}{I} = M \log \frac{I_0}{I},$$

where log stands for the natural logarithm and $M = \log e \doteqdot 0.4343$. For a perfectly transparent film, $I = I_0$ and $D = 0$ (no "density," no blackening). With decreasing transparency (I decreasing) the photographic density D increases steadily and for $I \to 0$, $D \to \infty$. For example, for $I = \frac{1}{10}$ or $\frac{1}{100} I_0$, $D = 1$ or 2.

If the incident light (I_0) is collimated, say, striking the film normally and if the transmitted intensity I comprises only normal light rays (all

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[2] That is to say, the total intensity of the radiation striking the front face of a film *less* the intensity reflected therefrom.

scattered or diffracted rays being excluded), we speak of the ratio $I:I_0$ as the *specular transparency* and consistently if $D = \log \frac{I_0}{I}$ as the specular density. It is usually denoted by D''. On the other hand, if the incident light is diffuse and if (as in applying the well-known integrating sphere) I comprises rays scattered in all directions, the transparency T of the film and the corresponding density $D = -\log T$ are called diffuse and, whenever the need arises, the latter is denoted by D^*.

Basing ourselves upon the quantum theory of exposure, we have derived the number k of grains of any given size a made developable by any given exposure E. Suppose for simplicity that the opacity of the film itself (even with the layer of the intact emulsion) is wholly negligible. Then, if the k developable grains, out of a total number N of grains spread over unit area, are actually developed (blackened), the film acquires a certain opacity and a corresponding density D.

In order to utilize the formulae for k/N, we must now express the photographic density D in terms of the number k of blackened grains and their size (area).

Let us first take up the question of the *specular* density, retaining for it the simple capital D instead of the cumbersome symbol D''.

To begin with, let the N grains (flat targets) spread over the film of area S_1 to be taken ultimately as our unit, be all of equal size a. Let k of these grains be blackened. If no account is taken of the mutual shielding or overlapping of these grains, then the total area of the blackened grains is simply ak,* and therefore the transparency of the film, after exposure and development,

$$T = 1 - ak$$

and the corresponding photographic density,

$$D = -\log (1 - ak). \tag{1}$$

Manifestly, however, the neglect of shielding of grains by other grains is justified only in the case of very thin emulsion coating, such as the so-called "single layer" coatings, made especially for microphotographic experiments. In all other cases, and notably in practical photography, it is necessary to take full account of shielding or overlapping, which will be seen presently to modify the results to a considerable extent.

To find the effect of mutual shielding of the silver halide targets of grains, it may be well to consider first the following simple situation: A circular grain (disk) of radius r or area $a = \pi r^2$ is placed on a film of unit area which we shall ultimately assume to be much larger than a.

* In this product, a is actually the area of the developed grain which will, in general, differ considerably from the area of the undeveloped grain appearing in our variable y.

A second grain or disk, of equal shape and size is thrown haphazardly upon the film. What is the probable area of overlapping of the two disks or grains?

The probability that the center of the second grain shall fall within a distance ρ to $\rho + d\rho$ from the center of the first grain is $2\pi\rho d\rho$ and the corresponding overlapped area is

$$\tilde{\omega} = 2r^2\theta - r\rho \sin\theta$$

where $\cos\theta = \rho/2r$. There is overlapping when and only when $0 < \rho < 2r$. Thus, the probable area of overlapping of the two grains is

$$[\tilde{\omega}] = 2r \int_0^{2r} (r\theta - \tfrac{1}{2}\rho \sin\theta) - 2r\rho d\rho.$$

If we put $u = 2\theta$, then

$$[\tilde{\omega}] = 2\pi r^4 \int_\pi^0 (\sin u - u) \sin u du = \pi^2 r^4$$

or

$$[\tilde{\omega}] = a^2.$$

Replacing S, the area of the film, hitherto taken as unity, we have

$$[\tilde{\omega}] = a \cdot \frac{a}{S}.$$

Now, imagine a number k of such (opaque) grains, all of size a, thrown haphazardly one by one upon our film of unit area. Then, the effectively covered area of the first grain itself being $\sigma_1 = a$, that of the first two grains jointly will be

$$\sigma_2 = a + a(1 - a) = a + (1 - a)\sigma_1,$$

since the contribution of the second grain is $a - a^2$. Add haphazardly one more grain. Then, the effective area of all three grains will be

$$\sigma_3 = \sigma_2 + a(1 - \sigma_2) = a + (1 - a)\sigma_2$$

or

$$\sigma_3 = a[1 + (1 - a) + (1 - a)^2],$$

and so on. The effective area of all k grains of size a strewn haphazardly over the film will be

$$\sigma_k = a[1 + (1 - a) + (1 - a)^2 + \cdots + (1 - a)^{k-1}]$$

or

$$\sigma_k = 1 - (1 - a)^k. \tag{2}$$

The k grains being opaque, the transparency of the film will be $1 - \sigma_k = (1 - a)^k$ and, therefore, its photographic density,

$$D = -M \cdot k \log (1 - a).$$

In this formula, a stands actually for the ratio of a grain's area to the film area S considered, and since the latter is, in all macroscopic cases, such as to contain a huge number (k) of grains, a is a small fraction, so that its square and higher powers are, to all purposes, negligible, $\log (1 - a) \doteqdot -a$, and therefore,

$$D = M \cdot ka = MF, \tag{3}$$

where F is the total, unreduced area of all k grains.

Returning to formula (2), notice that for large k, $(1 - a)^k = \left(1 - \frac{F}{k}\right)^k$ tends to e^{-F}. Thus, the expression for the effective area of k grains of size a may be written

$$\sigma_k = 1 - e^{-F} = 1 - e^{-ka}. \tag{2'}$$

The transparency of the film is now expressed by $T = e^{-F}$, whence $D = -\log T = MF$, as before.

The formula (3), derived for the case of equal grains, can be shown to hold also (at least approximately) for an emulsion consisting of grains of different sizes. If k be the number of blackened grains of size a, then

$$D = MF = M\Sigma aka, \tag{4}$$

where F is again the unreduced total area of all *blackened* grains. The sum extends over all sizes. If $f(a)$ is the size-frequency function of the emulsion (expressing its "size-frequency distribution"), so that $Nf(a)da$ is the number of grains of size a to $a + da$, over unit area of the unexposed film and, say,

$$N\phi_a(E) \cdot f(a)da,$$

the number of such grains after an exposure E and development, then, by (4),

$$D = MN \int_0^\infty \phi_a(E) a f(a) da. \tag{5}$$

The function ϕ of the exposure expressing the micrographic exposure law, will generally contain also the grain size a as parameter.

All this is, of course, wholly independent of any theory of exposure. If we accept the quantum theory of exposure, then the function ϕ assumes the form

$$\phi_a(E) = 1 - e^{-y}\left(1 + y + \cdots + \frac{y^{r-1}}{(r-1)!}\right) \tag{6}$$

where $y = \epsilon an$, $n = \frac{\lambda}{hc} E$, and r is the number of quanta required for the developability of a grain.[3]

[3] This number (r) is here assumed to be the same for all grains of the emulsion, whatever their size a.

If the size-frequency, $f(a)$, of an emulsion is known, it is enough to substitute it, alongside with (6) for $\phi_a(E)$ in the formula 5 and to evaluate the integral extended over all sizes present in order to find explicitly the density D produced by any given exposure E, provided that the question of the value of the quantum number r is settled.

Formula (5) with the meaning (6) of $\phi_a(E)$ and with any form of the function $f(a)$ is thus the general quantic expression for the density D as function of the exposure.

We shall now apply this general formula to a few particular cases, that is, to emulsions characterized by a few simple forms of the size-frequency function $f(a)$.

UNIFORM EMULSION

Let the emulsion consist of grains of *equal* size a, N being their number over unit area of the film. Then, returning to (3), we have directly

$$D = Mka = MN\phi_a(E) \cdot a$$

and by (6), under the r-quantic hypothesis,

$$D = MNa \left\{ 1 - e^{-y} \sum_{k=0}^{r-1} \frac{y^k}{k!} \right\}. \tag{7}$$

For $E \to \infty$ or $y \to \infty$, $D \to MNa$ (all grains blackened). Thus, of this limiting density, the extreme density of which the photographic film is liable, is denoted by D_m, our formula becomes

$$D = D_m \left\{ 1 - e^{-y} \sum_{0}^{r-1} \frac{y^k}{k!} \right\}. \tag{7}$$

This is simply our microphotographic, r-quantic formula of the characteristic curve with $\frac{k}{N}$ replaced by the macroscopic entity D/D_m. As before, the shape of the characteristic, D, $\log E$, or D, $\log y$, curves for $r = 1, 2$, and so on, is identically the same. The inflection point of the curve corresponding to (7) is, as before, for any r

$$\bar{y} = r \tag{7.1}$$

and its "contrast" or gamma, only with N replaced by D_m

$$\gamma = \frac{D_m}{M} \frac{(r/e)^r}{(r-1)!} \tag{7.2}$$

and thus, for $r = 1$, $\gamma = D_m/Me$, for $r = 2$, $\gamma/D_m = 4D_m/Me^2$ and so on.

EXPONENTIAL EMULSION

Such will be, with the reader's liberal consent, our short name for an emulsion with a simple exponential size-frequency distribution.[4] As before, let $f(a)da$ stand, in general, for the fraction of all grains (over unit area) whose sizes range from a to $a + da$, and let, in the present case,

$$f(a) = Ce^{-ua},$$

where C and u are constants. Since, by the definition of f,

$$1 = \int_0^\infty f(a)da = C\int_0^\infty e^{-ua}\,da = \frac{C}{u},$$

we have, in the first place, $C = u$ and

$$f(a) = ue^{-ua}.$$

Next, the average or mean grain size is

$$\bar{a} = \int_0^\infty af(a)da = u\int_0^\infty ae^{-ua}\,da$$

or

$$\bar{a} = \frac{1}{u}\int_0^\infty ue^{-u}\,du = \frac{1}{u}.$$

Ultimately, therfore, our function becomes

$$f(a) = e^{(-a/\bar{a})/\bar{a}}. \tag{8}$$

Substituting this in (5) and writing $\phi_a(y)$ instead of $\phi_a(E)$, we have

$$D = \frac{MN}{\bar{a}}\int_0^\infty a\phi_a(y)\,e^{-a/\bar{a}}\,da.$$

For $E \to \infty$ or $y \to \infty$, $\phi \to 1$, whatever the value of a, and $D \to D_\infty$. Consequently,

$$D_\infty = \frac{MN}{\bar{a}}\int_0^\infty ae^{-a/\bar{a}}\,da$$

$$D_\infty = MN\bar{a}\int_0^\infty ue^{-u}\,du = MN\bar{a},$$

as was to be expected. Thus $MN = D_\infty/\bar{a}$, and our last formula may, more conveniently, be written

$$\frac{D}{D_\infty} = \frac{1}{\bar{a}^2}\int_0^\infty a\phi_a(y)\,e^{-a/\bar{a}}\,da$$

[4] The case of some actual photographic emulsions (especially the "experimental," if not the commercial ones) can be roughly covered by a simple exponential function of a, provided that the smallest grains are disregarded.

or, putting $a/\bar{a} = u$

$$\frac{D}{D_m} = \int_0^\infty \phi_r(y)\, ue^{-u}\, du, \tag{9}$$

where, as in (6),

$$\phi_r(y) = 1 - e^{-y} \sum_0^{r-1} \frac{y^k}{k!}$$

and $y = n\epsilon a = n\epsilon\bar{a} \cdot u$. This holds for any quantum number r. For $r = 1$ (*one*-quantic hypothesis), we have $\phi = 1 - e^{-y}$ and

$$\frac{D}{D_m} = 1 - \int_0^\infty ue^{-(u+y)}\, du.$$

The integral is,

$$\int_0^\infty ue^{-(1+n\epsilon\bar{a})u}\, du = \frac{1}{(1 + n\epsilon\bar{a})^2},$$

provided that ϵ is assumed to be independent of a. Since $y = n\epsilon a$, let us write $n\epsilon\bar{a} = \bar{y}$. Then, our last result will become,

$$\frac{D}{D_m} = 1 - \frac{1}{(1 + \bar{y})^2}$$

or

$$\frac{D}{D_m} = \frac{\bar{y}(2 + \bar{y})}{(1 + \bar{y})^2}. \tag{9.1}$$

This, then, is the density-exposure law under the *one*-quantic hypothesis. The integration over all grain sizes has knocked out the exponential function and the density is now a rational algebraic function of the exposure variable $\bar{y}$.

In much the same way, although with some technical toil, we might treat the general case of any r. But it is much simpler to proceed as follows: returning to (9) and noticing that $y = \bar{y}u$, consider first the derivative $dD/d\bar{y}$ of the density rather than the density itself. Then, and since,

$$d\phi/d\bar{y} = \frac{d\phi}{d\bar{y}}\, u = \frac{u^r\, \bar{y}^{r-1}}{(r-1)!}\, e^{-\bar{y}u},$$

$$\frac{1}{D_m}\frac{dD}{d\bar{y}} = \frac{\bar{y}^{r-1}}{(r-1)!} \int_0^\infty u^{r+1}\, e^{-(1+\bar{y})u}\, du$$

$$= \frac{1}{(r-1)!}\, \frac{\bar{y}^{r-1}}{(1 + \bar{y})^{r+2}} \int_0^\infty x^{r+1}\, e^{-x}\, dx$$

and since the integral amounts to $(r+1)!$,

$$\frac{dD}{d\bar{y}} = D_m r(r+1)\cdot\frac{\bar{y}^{(r-1)}}{(1+\bar{y})^{r+2}}.$$

Thenceforth write, for brevity, y instead of $\bar{y} = n\epsilon\bar{a}$, so that

$$\frac{dD}{dy} = D_m r(r+1)\cdot\frac{y^{(r-1)}}{(1+y)^{r+2}}, \tag{10.r}$$

whence, integrating with respect to y, and noticing that $D = 0$ for $y = 0$ (no exposure, no density),

$$\frac{D}{D_m} = \frac{y^r(r+1+y)}{(1+y)^{r+1}},\ y = \epsilon\bar{a}n. \tag{9.r}$$

This is the required formula for the density as function of the exposure, valid for any quantum number r. The reader will instantly verify by differentiation that it satisfies (10) and, of course, the condition $D = 0$ for $y = 0$. Our previous formula (9.1) is but a particular case of (9.r), namely, for $r = 1$, and with $\bar{y}$ now denoted by y.

The gradient of the curve $D/\log y$ corresponding to (9.r) is

$$g(y) = \frac{y}{M}\frac{dD}{dy}, \text{ that is, by (10.}r\text{)},$$

$$g(y) = \frac{D_m r(r+1)}{M}\frac{y^r}{(1+y)^{r+2}}.$$

The inflection point, $y = \bar{y}$, of the curve, at which $g(y)$ attains its maximum γ, is determined by the equation $g'(y) = 0$, that is, by

$$r(1+y) = y(r+2),$$

whence

$$\bar{y} = \frac{r}{2}, \tag{11}$$

just one-half the quantum number in question, whence also $\gamma = g\left(\frac{r}{2}\right)$,

$$\gamma = \frac{D_m}{M}r(r+1)\frac{(r/2)^r}{\left(1+\frac{r}{2}\right)^{(r+2)}}$$

or, the *relative contrast* or relative gamma, as γ/D_m, may be called,

$$\gamma/D_m = \frac{1}{M}\frac{4(r+1)\cdot r^{r+1}}{(r+2)^{r+2}}. \tag{12}$$

Its first few values for $r = 1, 2, 3, 4$ are

$$\gamma/D_m = \frac{8}{27M'}, \frac{3}{8M'}, \frac{1296}{3125M'}, \frac{5}{M}\left(\frac{2}{3}\right)^6.$$

Numerically, to three decimals $\left(\text{recalling that } \frac{1}{M} = 2{,}303\right)$:

$$\gamma/D_m = 0.682,\ 0.863,\ 0.955,\ 1.011. \tag{12a}$$

With increasing quantum number, the relative gamma increases steadily rather slowly, tending to a finite limit. In fact, for $r \to \infty$, the factor of $1/M$ becomes $\dfrac{4}{\left(1 + \dfrac{2}{r}\right)^r}$ which tends to $4/e^2$. Thus, the asymptotic value of the relative contrast is

$$(\gamma/D_m)_{r=\infty} = \frac{4}{Me^2} \doteqdot 1.247. \tag{12b}$$

Such is the case for an exponential emulsion. It may be interesting to note that the relative contrast of a uniform emulsion, which is given by formula (7.2), becomes, for great r, $\gamma/D_m = \dfrac{1}{M}\sqrt{\dfrac{r}{2\pi}}$, and thus increases with r indefinitely. Its leading value, for $r = 1$, is perceptibly greater than for an exponential emulsion, *viz.* $\gamma/D_m = \dfrac{1}{Me} = 0.847$. For $r = 2$, we have, for a uniform emulsion,

$$(\gamma/D_m)_{r=2} = \frac{4}{Me^2} \doteqdot 1.247 \qquad \text{(uniform)},$$

which is identical with the relative contrast of an exponential emulsion for $r = \infty$ or, practically, for a huge quantum number r. We may say, summarily, that an emulsion consisting of equal grains (or nearly so) is much more "contrasty" than an exponential emulsion or an emulsion with a very wide range of grain sizes.

Returning to formula (9.r), valid for an *exponential* emulsion, we have, for $r = 1, 2, 3$, respectively,

$$\begin{aligned} D/D_m &= \frac{y(y+2)}{(y+1)^2} \equiv E(y), \\ D/D_m &= \frac{y^2(y+3)}{(y+1)^3} \equiv F(y), \\ D/D_m &= \frac{y^3(y+4)}{(y+1)^4} \equiv G(y). \end{aligned} \tag{13}$$

The short symbols $E(y)$, $F(y)$, $G(y)$, will, in the sequel, be constantly used in our concrete applications of these quantic formulae and the corresponding characteristic curves, D, $\log y$. These three algebraic functions of the exposure, with the abcissae y spaced logarithmically, are drawn in Fig. 1. They will be seen to differ appreciably from the curves $\frac{D}{D_m}$, $\log y$ for a uniform emulsion (Fig. 2).

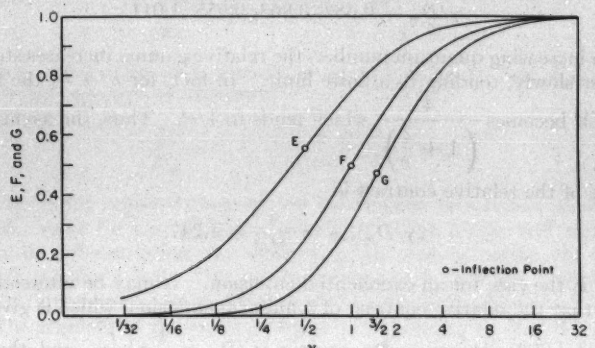

FIG. 1.

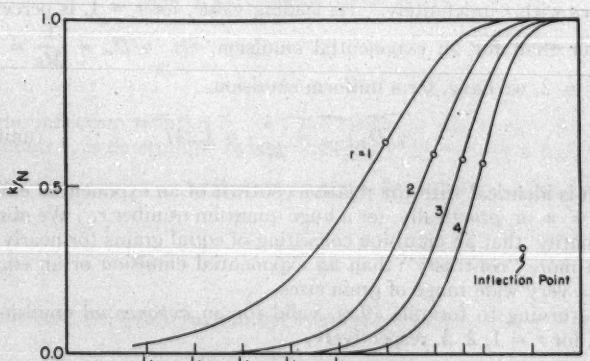

FIG. 2.

These three functions, E, F, G, deserve some particular attention since they have turned out to cover, singly or in binary combinations, the characteristic curves of almost all experimental emulsions hitherto investigated, as will be seen later on.

Needless to say, all these functions vanish for $y = 0$ and tend to unity for $y \to \infty$. A numerical table of E, F, G, sufficient for all practical purposes is given below.

y	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1	2	4	8	16	32
E	0.030	.060	.114	.210	.360	.556	0.750	.889	.960	.988	.997	1.000
F	0.000_7	.003	.010	.034	.104	.259	0.500	.741	.896	.966	.990	0.997
G	0.000	.000	$.000_8$	.005	.027	.111	0.313	.592	.819	.937	.981	0.994

The inflection point of the D, $\log y$ curve, for any r, is placed at $y = \bar{y} = r/2$. Thus, the inflection points of the curves corresponding to E, F, G are, respectively,

$$\bar{y} = \tfrac{1}{2}, 1, \tfrac{3}{2}.$$

As we see from the table, $E(\frac{1}{2})$ exceeds $\frac{1}{2}$ by 0.056 so that the *one*-quantic curve of an exponential emulsion cannot be symmetrical. Again, $G(\frac{3}{2}) = \dfrac{297}{625} = 0.475 = \frac{1}{2} - 0.025$, so that the *three*-quantic curve is again asymmetrical. So also are all curves $(9.r)$ for $r = 4, 5$, and so on. The only symmetrical curve of this family is the *two-quantic* one, corresponding to $\dfrac{D}{D_m} = F(y)$. In fact, by the definition of this function we have, for any y,

$$F\left(\frac{1}{y}\right) = \frac{1 + 3y}{(1 + y)^3} = 1 - \frac{3y^2 + y^3}{(1 + y)^3} = 1 - F(y),$$

so that

$$F(y) + F\left(\frac{1}{y}\right) = 1,$$

which proves the rigorous (rotational) *symmetry* of the curve $F(y)$, $\log y$, A rigid rotation of the curve through 180 deg. about its inflection point $(\bar{y} = 1)$ brings the curve into congruence with itself, its toe and shoulder being exchanged.[8]

As has already been mentioned, the quantic curves (*viz.* for $r = 1, 2, 3$) based on the assumption of an exponential size-frequency function $f(a)$ suffice for a close representation of practically all characteristic curves observed on experimental emulsions.

Nonetheless, it may be instructive to consider one more form of the size-frequency function $f(a)$ appearing in our general formula (5), namely, the Gaussian or "Normal" function. Hypothetical emulsions endowed with such a size-frequency distribution may be briefly referred to as "Gaussian."

[8] In fine, the *two-quantic* characteristic curve of an *exponential* emulsion is its only symmetrical quantic curve, while all quantic curves of a *uniform* emulsion are asymmetrical.

GAUSSIAN EMULSIONS

The most general size-frequency of the Gaussian or "Normal" type can be written

$$f(a) = Ce^{-k^2(a-a_1)^2}, \tag{14}$$

where C, k, and a, are (positive) constants or parameters. The parameter a_1 is, manifestly, the most frequent grain size, its frequency being $f(a_1) = C$. Since $f(a_1 + x) = f(a_1 - x)$, both frequencies being $Ce^{-k^2x^2}$, the graph of the function (14) is a curve symmetrical about its peak $a = a_1$. The whole curve, however, is non-symmetrical, since it extends indefinitely beyond a_1, while below a, it terminates, of course, at $a = 0$, where its ordinate is

$$f(0) = Ce^{-k^2a_1^2}.$$

Let us now introduce the function (14) into our general formula (5) with $\phi(E)$ or $\phi(y)$ having the quantic meaning (6).

In the first place, since for $y = \infty$, $D = D_m$ and, at the same time, $\phi(\infty) = 1$, we have

$$D_m = MN\int_0^\infty af(a)da.$$

But the integral is equal to the *mean* grain size, so that

$$D_m = MN\bar{a},$$

which we already know to hold for any size-frequency distribution. At any rate, we may now conveniently write instead of (5),

$$\frac{D}{D_m} = \frac{1}{\bar{a}}\int_0^\infty \phi(y)af(a)da. \tag{5'}$$

Thus, in our present case

$$\bar{a}\frac{D}{D_m} = C\int_0^\infty \phi(y)ae^{-k^2(a-a_1)^2}\,da \tag{15}$$

where, as before, $y = n\epsilon a$. We shall assume that ϵ is constant, that is, independent of a.

Let us first consider the *one-quantic* hypothesis, so that

$$\phi(y) = 1 - e^{-y},$$

and (15) becomes

$$\bar{a}\frac{D}{D_m} = C\int_0^\infty ae^{-k^2(a-a_1)^2}\,da - C\int_0^\infty ae^{-k^2(a-a_1)^2-n\epsilon a}\,da$$

or, since the first term is simply $\bar{a}$,

$$\frac{D}{D_m} = 1 - (C/\bar{a}) \cdot \int_0^\infty a e^{-k^2(a-a_1)^2 - s \cdot a} \, da. \tag{16}$$

It will be recalled that $\int_0^\infty f(a)da = 1$, and thus, in our present case,

$$1 = C \int_0^\infty e^{-k^2(a-a_1)^2} \, da = \frac{C}{k} \int_{-ka_1}^\infty e^{-u^2} \, du$$

or, in terms of the error function

$$\Phi(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-u^2} \, du,$$

$$1 = \frac{\sqrt{\pi}}{2} \frac{C}{k} \{1 + \Phi(ka_1)\}.$$

Thus, the parameter C is completely determined by k and a_1,

$$C = \frac{2k}{\sqrt{\pi} \{1 + \Phi(ka_1)\}}. \tag{17}$$

If, in particular, ka_1, exceeds a few units, $\Phi(ka_1) \doteq 1$, and the relation reduces to $C = \frac{k}{\sqrt{\pi}}$, so that the frequency function (14) becomes

$$f(a) = \frac{k}{\sqrt{\pi}} e^{-k^2(a-a_1)^2}.$$

The mean grain size is, by definition,

$$\bar{a} = C \int_0^\infty a e^{-k^2(a-a_1)^2} \, da = \frac{Ca_1}{k} \int_{-ka_1}^\infty e^{-x^2} \, dx + \frac{C}{k^2} \int_{-ka_1}^\infty x e^{-x^2} \, dx.$$

The first term is, by (17) equal to a_1, and the second integral amounts to $\frac{1}{2} e^{-k^2 a_1^2}$, so that

$$\bar{a} = a_1 + \frac{C}{2k^2} e^{-k^2 a_1^2}$$

or, again by (17),

$$\bar{a} = a_1 + \frac{e^{-k^2 a_1^2}}{k \sqrt{\pi} \{1 + \Phi(ka_1)\}}. \tag{18}$$

With increasing ka_1, the mean grain size $\bar{a}$ tends rapidly to a_1, the most frequent size.

Turning to the density formula (16), we have

$$\frac{D}{D_m} = 1 - (C/\bar{a}) \cdot I,$$

where I is the integral in the second term of (16). Since

$$k^2(a - a_1)^2 + n\epsilon a = k^2(a - b)^2 + bn\epsilon + \frac{n^2\epsilon^2}{4k^2}, \tag{19}$$

where

$$b = a_1 - \frac{n\epsilon}{2k^2},$$

the required integral is

$$I = e^{-bn\epsilon - (n^2\epsilon^2/4k^2)} \int_0^\infty a e^{-k^2(a-b)^2}\, da.$$

The last integral is of the form of the integral just evaluated, only with a_1 replaced by b, so that

$$I = \frac{\sqrt{\pi} b}{2k} \{1 + \Phi(bk)\}\, e^{k^2(b^2 - a_1^2)} + \frac{1}{2k^2} e^{-k^2 a_1^2}.$$

Ultimately, therefore, we have by (17) and (18), after simple reductions, the *one*-quantic density-exposure formula

$$\frac{D}{D_m} = 1 - \frac{1 + \sqrt{\pi}\, bk\, \{1 + \Phi(bk)\}\, e^{k^2 b^2}}{1 + \sqrt{\pi}\, a_1 k\, \{1 + \Phi(a_1 k)\}\, e^{k^2 a_1^2}}, \tag{20a}$$

where $b = a_1 - \dfrac{\epsilon n}{2k^2} = a_1 - \dfrac{\epsilon\lambda}{2nck^2} E$, $E = \dfrac{hc}{\lambda} \cdot n$ being the exposure, that is, the incident radiation energy per unit area of the film.

For $E = 0$, $b = a_1$ and $D = 0$. For $E \to \infty$ we have $bk = -m$, where $m \to \infty$. Thus, the well-known property of the error-function, the second term of the numerator of the fraction appearing in (20a) is

$$-\{1 - \Phi(m)\}\, \sqrt{\pi}\, m e^{-m^2} = -1,$$

and we are left with $D = D_m$, as it should be.

Notice that the numerator of that fraction is exactly the same function of the variable kb, as is the numerator of the constant ka_1, so that the formula may be conveniently written

$$\frac{D}{D_m} = \frac{R(ka_1) - R(kb)}{1 + R(ka_1)}, \tag{20}$$

where

$$R(x) = \sqrt{\pi}\, x\, \{1 + \Phi(x)\}\, e^{x^2} \tag{21}$$

and, as before, $kb = ka_1 - \dfrac{\epsilon\lambda}{2hck} E$.

The function $R(x)$, for the argument $x = ka_1$, has a simple geometrical meaning. In fact, the expression (18) for $\bar{a}$ can be written

$$\bar{a} : a_1 = 1 + 1/R(ka_1), \tag{18a}$$

so that $R(ka_1) = a_1:(\bar{a} - a_1)$, the ratio of the most frequent size to the excess of the mean over the most frequent size.

If ka_1 amounts only to a few units, $\bar{a}$ is but slightly greater than a_1, for example, for $ka_1 = 2$, $\Phi(2) = 0.9953$ and $R(2) = 386.3$, so that $\bar{a} = 1.0026a_1$. Even for $ka_1 = 1$, $R(ka_1) = 8.878$ and $\bar{a}$ exceeds $\bar{a}_1$ by 11 per cent only.

The standard deviation s of the distribution, which is defined by

$$s^2 = \overline{(a - \bar{a})^2} = \overline{a^2} - \bar{a}^2$$

or $s^2 = [a^2] - [a]^2$, is in the present case found to be rigorously

$$s^2 = \frac{1}{2k^2} + (\bar{a} - a_1)(2a_1 - \bar{a}). \tag{22}$$

Approximately, if $\bar{a}$ differs but little from a_1,

$$s = \frac{1}{k\sqrt{2}}. \tag{22a}$$

If, for instance, $ka_1 = 2$, we have, by (22),

$$s^2 = \frac{1}{2k^2}\{1 + 0.020\} \text{ or } s = \frac{1.01}{k\sqrt{2}}.$$

In fine, for considerable values of ka_1, such as 2.5 or 3, the parameter k is inversely proportional to the standard deviation or (as it is often called) "the spread" of the size-distribution curve. The greater ka_1, the more slender the curve. In the limit, $ka_1 = \infty$, the emulsion consists of equal grains (uniform) emulsion.

Put $\alpha = a_1:\bar{a}$, so that α will be a proper fraction (tending to unity for increasing ka_1). Then, by (18a), the formula (20) may be conveniently written,

$$\frac{D}{D_m} = \alpha - (1 - \alpha)R(kb).$$

There α is a constant, an attribute of the emulsion, and the variable exposure enters only through $bk = ka_1 - \frac{\epsilon\lambda}{2hck}E$.

Let us introduce, for an emulsion with Gaussian grain size distribution, as our exposure variable,

$$y = \frac{\epsilon\lambda}{2hck}E. \tag{23}$$

Then, the last equation will ultimately become

$$\frac{D}{D_m} = \alpha - (1 - \alpha)R(u),$$

$$u = ka_1 - y, \; \alpha = a_1 : \bar{a}. \tag{24}$$

This form, with y proportional to the exposure E, as the only variable, will be convenient for any further discussion or numerical application.

The *gradient* of the characteristic curve (D, log y) is

$$g = \frac{y}{M}\frac{dD}{dy} = -\frac{y}{M}D'(u)$$

and thus, by (24),

$$\frac{g}{D_m} = \frac{1}{M}(1 - \alpha)\, yR'(u), \tag{24.1}$$

where, by (21), $R'(u) = \left(2u + \frac{1}{u}\right) R(u) + 2u.$

The *inflection point* of the curve corresponds to $g'(u) = 0$ and is, therefore, determined by

$$\frac{R'(\bar{u})}{R''(\bar{u})} = ka_1 - \bar{u}, \tag{24.2}$$

where R' is as above and $R''(u) = 2(3 + 2u^2)\, R(u) + 4(u^2 + 1)$. Thus (24.2) is a very complicated transcendental equation for the inflection point $y = \bar{y} = ka_1 - \bar{u}$. The laborious method of solving it by successive approximations can be avoided by a simple artifice. The transcendental equation (24.2) is equivalent to an algebraic one of infinite degree, and must, therefore, have an infinity of roots $\bar{u}$, some real and some conjugate complex ones in pairs. Now, as preliminary graphs have shown, the curve (24), with log y as abscissa, has only *one* inflection point. If, therefore, we find a root $\bar{u}$ of (24.2) by any method whatever, for a given emulsion, that is to say, for a given ka_1, that root will be the required one (all others will be complex). Now, instead of finding from (24.2) the approximate real value of u corresponding to a given ka_1, we shall invert the process and compute, for a number of u-values, the value of

$$ka_1 = u + R'(u)/R''(u),$$

retaining, of course, only such cases which lead to a *positive* ka_1. Thus, for example, taking $u = 0$ and noticing that $R(0) = 0$, $(R/u)_{u=0} = \sqrt{\pi}$ and $R'(0) = \sqrt{\pi}$, $R''(0) = 4$, we have

$$ka_1 = \tfrac{1}{4}\sqrt{\pi}$$

and, since $y = ka_1 - u$,

$$\bar{y} = \tfrac{1}{4}\sqrt{\pi} = 0.4431.$$

Similarly we have found, for $u = 1$,

$$ka_1 = 1.2959 \text{ and } \bar{y} = 0.2959.$$

In this manner the following table has been prepared.[6] The originally computed four decimals were rounded off to three, which will suffice for all purposes.

Inflection Point

$\bar{u} =$	−0.300	−0.200	−0.100	0.000	0.500	0.661	0.750	1.000	2.000
$ka_1 =$	0.199	0.280	0.361	$\frac{\sqrt{\pi}}{4}$	0.861	1.000	1.077	1.296	2.205
$\bar{y} =$	0.499	0.480	0.461	0.443	0.361	0.339	0.327	0.296	0.205

The inflection exposure $\bar{y} = \frac{1}{2}\left(\frac{\epsilon\lambda}{hc}\right)\frac{\bar{E}}{k}$ decreases steadily with increasing ka_1 (that is, when the size-frequency curve becomes more and more slender). Within the limits of our table, $\bar{y}$ is, nearly enough, a linear function of ka_1, to wit,

$$\bar{y} = 0.532 - \tfrac{1}{8}\, ka_1. \tag{24.3}$$

The value of γ for an emulsion characterized by a given ka_1 and $\alpha = \bar{a}:a_1$ is, by (24.1),

$$\gamma = \frac{D_m}{M}(1 - \alpha)\,\bar{y}R'(\bar{u}), \tag{24.4}$$

that is,

$$\gamma = \frac{D_m}{M}(1 - \alpha)\,\bar{y}(2\bar{u} + 1/\bar{u})\,R(\bar{u}).$$

The simple numerical factor 8/27, valid under the *one-quantic* hypothesis for an exponential emulsion is now replaced by $(1 - \alpha)\bar{y}R'(\bar{u})$, a complicated function of ka_1, with $1 - \bar{a}/a_1$ as factor.

To form an adequate idea about the characteristic curves corresponding to formula (24), it will suffice to treat numerically the case of a moderate ka_1-value, say 1, and the two extreme cases, of evanescent and of infinite ka_1, corresponding to a *very broad* and to a *very slender* size-frequency curve of the emulsion.

I. $ka_1 = 1$.

$R(1) = 8.88$ and, by (18*a*), $\gamma = 0.899$, $u = 1 - y$, so that formula (24) becomes

$$D/D_m = 0.899 - 0.101\,R(1 - y). \tag{24.I}$$

[6] Only the u-value for $ka_1 = 1$ has been found by interpolation between $u = \frac{1}{2}$ and $\frac{3}{4}$.

This gives the following set of relative densities (D/D_m):

$y =$	0.01	0.02	0.04	0.08	0.16	0.32	0.64	1.00	1.28	2.56	5.12
$D/D_m =$	0.028$_5$	0.056	0.109	0.204	0.261	0.567	0.797	0.899	0.936	0.986	0.997

The corresponding curve $\left(\frac{D}{D_m}, \log y\right)$ is shown in Fig. 3. By (24.4), $\gamma = \frac{0.0342}{M} R'(\bar{u}) D_m$, where $R'(\bar{u}) = 1.322 + 2.832\ R(\bar{u}) = 9.795$ so that

$$\gamma/D_m = 0.776. \qquad \text{(Gaussian)}.$$

This is intermediate between 0.682 and 0.847, the relative contrasts of the one-quantic curve for an exponential and a uniform emulsion, as might be expected.

Since in the common chart (Fig. 3) of the curve (24.*I*) and the following two extreme curves, the mean grain size $(\bar{a})$ instead of the most frequent one (a_1) will be used, we may note that, for $ka_1 = 1$, $a_1 = 0.899\ \bar{a}$ or

$$\log \bar{a} = \log a_1 + 0.0462.$$

II. $ka_1 = \infty$

This limiting case[7] of a Gaussian emulsion can be expected to be identical with that of a *uniform* emulsion (grains all equal). Such, in fact, is the case.

First of all, we have $a_1 = \bar{a}$ or $\alpha = 1$, and since $R(u) = R(ka_1 - y) = R(\infty) = \infty$, for all finite exposures y, the term $(1 - \alpha)\ R(u)$ in (24) becomes indeterminate. Let us, then, return to the original form, (20), of the density-exposure equation. Since both $R(ka_1)$ and $R(kb) = R(u)$ are infinite, and $a_1 = \bar{a}$, we have

$$\frac{D}{D_m} = 1 - \frac{R(u)}{R(k\bar{a})} = 1 - \frac{u[1 + \Phi(u)]\, e^{u^2}}{2k\bar{a}\, e^{k^2\bar{a}^2}},$$

where $u = k\bar{a} - y = k\bar{a}\left(1 - \frac{\epsilon\lambda}{2hc}\frac{E\bar{a}}{k^2\bar{a}^2}\right)$ tends to ∞, while $\Phi(u)$ and $u/k\bar{a}$ tend to 1. Thence, $\frac{D}{D_m} = 1 - e^{u^2 - k^2\bar{a}^2}$, and since $u^2 - k^2\bar{a}^2$ tends to $-\frac{\epsilon\lambda}{hc} E\bar{a} = -n\bar{a}\epsilon$, we have, ultimately,

$$\frac{D}{D_m} = 1 - e^{-n\bar{a}\epsilon}. \qquad (24.II)$$

[7] Which, as we saw, should be practically reached when ka_1 exceeds only some two or three units.

as for an emulsion whose grains are all of size $\bar{a}$ (the mean grain size of the Gaussian emulsion), in both cases under the *one*-quantic hypothesis. Notice that, if $\bar{a}$ is finite, $ka_1 = k\bar{a} = \infty$ implies $k = \infty$, so that, by (22) the standard deviation, $s = \dfrac{1}{k\sqrt{2}}$, vanishes, that is, the size-frequency curve of the Gaussian emulsion is infinitely slender or a mere vertical line, at $a = \bar{a}$. In fine, $ka_1 = \infty$ means "a uniform emulsion."

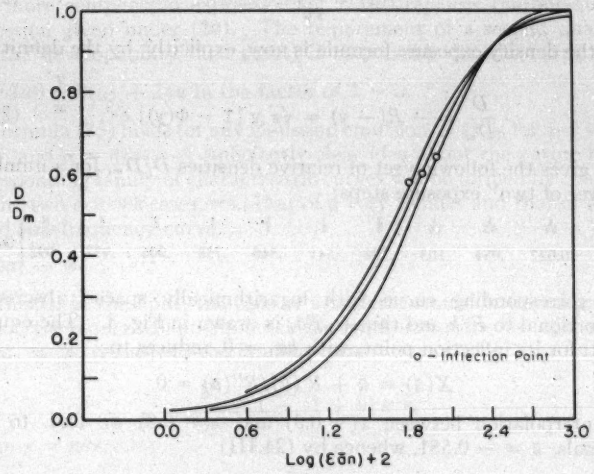

FIG. 3.

III. $ka_1 \to 0$

This, the other extreme, is the limiting case of a very broad size-frequency curve, with a standard deviation s much greater than a_1, the most frequent grain size.

Our formula (24) now reduces to $D/D_m = -R(u)$, where $u = -y \equiv \dfrac{-\epsilon\lambda}{2hc} \cdot \dfrac{E}{k}$. Thus we have

$$\frac{D}{D_m} = -R(-y).$$

Since $R(-\infty) = -1$, we have, for $E = \infty$, $D = D_m$, as it should be.

The coefficient k (appearing as divisor of the exposure E) is now simply related to the average grain size $\bar{a}$. For, since $R(ka_1)$ tends to

$\sqrt{\pi}\, ka_1$, we have, by (18a) and in view of $1/ka_1 \to \infty$

$$\bar{a} = a_1\left[1 + \frac{1}{\sqrt{\pi}\, ka_1}\right] = \frac{1}{\sqrt{\pi}\, k}$$

or

$$k = 1/\sqrt{\pi}\, \bar{a}.$$

The Gaussian distribution function assumes the form

$$f(a) = \frac{2}{\pi \bar{a}} e^{(-1/\pi)a^2/a-2}, \qquad (24.\text{III})$$

and the density exposure formula is now, explicitly, by the definition of R,

$$\frac{D}{D_m} = -R(-y) = \sqrt{\pi}\, y\, \{1 - \Phi(y)\}\, e^{y^2}. \qquad (24.\text{III})$$

This gives the following set of relative densities D/D_m, for a number of "power of two" exposure steps:

$y =$	$\frac{1}{64}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{2}$	1	2	4	8	
$\frac{D}{D_m} =$	0.027	.054	.103	.194	.341	.546	.758	.906	.972	.992	$(ka_1 = 0)$

The corresponding curve with logarithmically spaced abscissae y, proportional to E/k and thus to $E\bar{a}$, is drawn in Fig. 3. The equation (24.2) for its inflection point, with $ka_1 = 0$, reduces to

$$X(\bar{u}) \equiv \bar{u} + R'(\bar{u})/R''(\bar{u}) = 0.$$

By interpolation between $x(-0.3)$ and $x(-0.0)$ we find, to three decimals, $\bar{u} = -0.551$, whence by (24.III)

$$\bar{y} = 0.551 \text{ and } \bar{D} = 0.577\, D_m.$$

Finally, since $\alpha = 0$, we have $\gamma = 0.551\, D_m R'(\bar{u})/M$ which amounts to

$$\gamma/D_m = 0.736.$$

Collecting our results found under, I, II, and III, we have the following positions of the *inflection point* and γ-*values* for the three special emulsions with Gaussian grain-size distribution:

$ka_1 =$	0	1	∞
$\bar{y} =$	0.551	0.754	1.000
$\bar{D}/D_m =$	0.577	0.595	0.632
$\gamma/D_m =$	0.736	0.776	0.847

The relative contrast for all possible emulsions of this kind (always under the *one*-quantic assumption) is contained between 0.74 and 0.85, while the inflection point moves, with increasing ka_1 or decreasing standard deviation s, forward and upward, as shown also in Fig. 3.

So for the one-quantic hypothesis, $r = 1$. For higher values of r, the expressions for a Gaussian emulsion become rather unwieldy. We shall, therefore, limit ourselves to the case of $r = 2$, the *two*-quantic hypothesis. Proceeding as before, we find with the same meaning of the symbols, αy, u, $R(u)$,

$$\frac{D}{D_m} = \alpha - (1 - \alpha)\left\{\left[1 + \frac{1 + 2u^2y}{u}\right]R(u) + 2uy\right\}. \qquad (25)$$

This more complicated expression for D/D_m replaces the one-quantic expression given under (24). The requirement of a second quantum (for the developability of a grain) is responsible for the extra terms $(1 + 2u^2)\frac{y}{u}R(u) + 2yu$ in the factor of $1 - \alpha$.

Formula (25) holds for any Gaussian emulsion, that is, for any values of ka_1 and $\alpha = \bar{a}/a_1$. A sufficiently clear idea about the nature of the corresponding family of characteristic curves will be formed by considering the two *extreme* cases, *viz.*, that of a very slender and that of a very broad size-frequency curve.

I. $ka_1 \to \infty$

This is, in the limit, the case of a uniform emulsion (equal grains). In fact, the reader will find in much the same way as for $r = 1$, that (25) for $ka_1 = \infty$, reduces to the familiar form

$$\frac{D}{D_m} = 1 - (1 + y)\,e^{-y}, \qquad (25.\text{I})$$

where $y = n\bar{a}\epsilon$.

II. $ka_1 \to 0$.

In this case, u tends to $-y$ and α to zero, so that (25) becomes $D/D_m = 2u^2[1 + R(u)]$, and since $k = 1/\bar{a}\sqrt{\pi}$, we have

$$\frac{D}{D_m} = 2y^2[1 + R(1 - y)], \qquad (25.\text{II})$$

where $y = \frac{\sqrt{\pi}}{2}n\bar{a}\epsilon$, n being the exposure in quanta per unit area, as before $\left(n = \frac{h}{\pi c}E\right)$. The reader will easily ascertain that the bracketed expression is always positive. When the exposure increases from 0 to ∞, the function $R(-y)$ decreases from 0 towards -1, according to the easily derivable formula

$$R(-y) = -1 + \frac{1}{2y^2} - \frac{3}{4y^4} + \cdots.$$

Thus, for great exposures,

$$D = D_\infty \left(1 - \frac{3}{2y^2} + \cdots\right),$$

tending to D_∞. By (25.II), we find for the inflection point of the D, log y curve the complicated transcendental equation

$$R(-y) + \frac{2(2 + 7y^2 + 2y^4)}{9 + 16y^2 + 4y^4} = 0,$$

which is very nearly satisfied by $y = \bar{y} = 1$. In fact, $R(-1) = -0.7578$, while the second term for $y = 1$, is $\frac{22}{29} = 0.7586$. Thus the co-ordinates of the inflection point are

$$\bar{y} = 1, \; \bar{D} = 0.484\, D_\infty.$$

Finally, we have $\gamma/D_\infty = 2\bar{y}^2\{2(1 + \bar{y}^2) + (3 + 2\bar{y}^2)\, R(-\bar{y})\}$ and, therefore, with $\bar{y} = 1$, $R(-1) = -0.758$,

$$\gamma/D_\infty = 0.967, \; (r = 2),$$

which is considerably greater than 0.736 found above for the same emulsion on the *one*-quantic hypothesis. We may mention, also, that the exposure at the inflection point is now ($r = 2$) about twice that found for $r = 1$.

EMULSION WITH ANY SIZE-FREQUENCY $f(a)$

The general expression for the density as function of the exposure $n = \frac{\lambda}{hc} \cdot E$, under the r-quantic hypothesis, may be written (with $\bar{a} = [a]$)

$$\frac{D}{D_\infty} = 1 - \frac{1}{[a]} \int_0^\infty a f(a) e^{-n\epsilon a} \left\{1 + n\epsilon a + \cdots + \frac{(n\epsilon a)^{r-1}}{(r-1)!}\right\} da, \qquad (26)$$

where $D_\infty = MN[a] = MN \int_0^\infty a f(a) da$. The exponential function can be developed into a power series,

$$1 - n\epsilon a + \frac{(n\epsilon a)^2}{2!} - \frac{(n\epsilon a)^3}{3!} + \cdots.$$

Let us consider in some detail the case of the leading values of the quantum number r.

$$r = 1.$$

The bracketed expression in the integrand of (26) reduces to 1, so that the integral becomes

$$\int_0^\infty f(a)\left\{a - n\epsilon a^2 + \frac{(n\epsilon)^2}{2!}a^3 - \frac{(n\epsilon)^3}{3!}a^4 + \cdots\right\}da =$$

$$[a] - [a^2]n\epsilon + [a^3]\frac{n^2\epsilon^2}{2!} - [a^4]\frac{n^3\epsilon^3}{3!} + \cdots,$$

where $[a]$ is the mean grain size, $[a^2]$ the mean squared grain size, and so on.[8] Thus the density formula becomes

$$\frac{D}{D_m} = \frac{[a^2]}{[a]}n\epsilon - \frac{[a^3]}{[a]}\frac{n^2\epsilon^2}{2!} + \frac{[a^4]}{[a]}\frac{n^3\epsilon^3}{3!} - \cdots.$$

The first term, proportional to the exposure, has the coefficient $[a^2][a]^{-1}$. It will be recalled that the *standard deviation*, s, is defined by $s^2 = [a^2] - [a]^2$, so that the coefficient of $n\epsilon$ is

$$[a] + \frac{s^2}{[a]} = \bar{a} + s^2/\bar{a}.$$

The next term, proportional to the square of the exposure, has the coefficient $-\dfrac{[a^3]}{[a]}$. The skewness η of the distribution of sizes can be considered as defined by

$$\eta^3 = [(a - \bar{a})^3] = \overline{a^3} - 3\bar{a}\cdot\overline{a^2} + 2\bar{a}^3,$$

so that the coefficient of $-\dfrac{n^2\epsilon^2}{2!}$ is

$$\eta^3/\bar{a} + 3s^2 + \bar{a}^2,$$

and so on. If we take, for the moment, the mean grain size $\bar{a} = [a]$ as unit of all sizes (areas) implied, then our density formula can be conveniently written

$$\frac{D}{D_m} = \overline{a^2}\cdot\epsilon n - \overline{a^3}\frac{\epsilon^2 n^2}{2!} + \overline{a^4}\frac{\epsilon^2 n^3}{3!} - \cdots. \tag{26.1}$$

The relative density D/D_m, is a power series of the exposure, $\epsilon n = \dfrac{\lambda\epsilon}{hc}E$, with coefficients depending only on the size-frequency characteristics of the emulsion, $\overline{a^2}$, $\overline{a^3}$, and so on. The series starts, on the *one*-quantic hypothesis, with the *first power* of the exposure and has intermittently positive and negative terms.

$r = 2.$

[8] We have assumed here that ϵ, the intrinsic sensitivity of a grain per unit of its area, is independent of the grain's size a.

On the *two*-quantic hypothesis the bracketed factor in the integrand of (26) is $1 + n\epsilon a$. Proceeding as before and setting again $\bar{a} = 1$, the reader will find that the first power of the exposure disappears, the expansion of D starts with *the square* of the exposure and consists again of intermittently positive and negative terms, to wit,

$$\frac{D}{D_m} = \tfrac{1}{2}\overline{a^2}\cdot\epsilon^2n^2 - \tfrac{1}{3}\overline{a^3}\cdot\epsilon^3n^3 + \tfrac{1}{8}\overline{a^5}\cdot\epsilon^4n^4 - \cdots. \qquad (26.2)$$

Generally, for any r we have the expansion

$$\frac{D}{D_m} = \frac{(\epsilon n)^r}{r!}\left\{\overline{a^{r+1}} - \frac{r}{r+1}\overline{a^{r+2}}\cdot\epsilon n + \frac{r}{2!(r+2)}\overline{a^{r+3}}\cdot\epsilon^2n^2 - \frac{r}{3!(r+3)}\overline{a^{r+4}}\,\epsilon^3n^3 + \cdots\right., \qquad (26.r)$$

which starts with the rth *power* of the exposure. The terms are always intermittently positive and negative.

The slope or gradient of the corresponding characteristic curve is

$$g = \frac{E}{M}\frac{dD}{dE} = \frac{\epsilon n}{M}\frac{dD}{d(\epsilon n)},$$

since E differs from ϵn by a constant factor only. Thus by (26.r),

$$g/D_m = \frac{(\epsilon n)^{r-1}}{(r-1)!}\left\{\overline{a^{r+1}} - \overline{a^{r+2}}\,(\epsilon n) + \overline{a^{r+3}}\,\frac{\epsilon n^2}{2!} - \cdots\right\}. \qquad (27.r)$$

The D/log E curve, has, therefore, initially a contact of the $(r-1)^{st}$ order with the log E axis. The inflection point of the curve is determined by the non-vanishing root $\epsilon\tilde{n}$ of the equation $g' = dg/d\,(\epsilon n) = 0$, that is, of the equation

$$(r-1)[a^{r+1}](\epsilon n)^{r-2} - r[a^{r+2}](\epsilon n)^{(r-1)} + (r+1)[a^{r+3}]\frac{(\epsilon n)^2}{2!} - \cdots = 0.$$

Under the *one-quantic* hypothesis, for instance, we have

$$\frac{g}{D_m} = [a^2] - [a^3]\,(\epsilon n) + [a^4]\frac{(\epsilon n)^2}{2!} - \cdots, \qquad (r=1)$$

where $D_m = MN\bar{a} = MN$, since $\bar{a}$ is here our unit area. The slope of the curve is, initially, proportional to $[a^2]$, the mean squared grain size. Under the *two*-quantic hypothesis,

$$\frac{g}{D_m} = (\epsilon n)\left\{[a^3] - [a^4]\,(\epsilon n) + [a^5]\frac{(\epsilon n)^2}{2!} - \cdots\right\}, \qquad (r=2)$$

so that the slope itself vanishes initially, but its derivative with respect to the exposure is, initially, proportional to $[a^3]$, the mean of the cubed grain size, and so on.

This brings out the dependence of the sensitometric peculiarities of an emulsion on its size-frequency characteristics, *viz.*, the mean values of a^2, a^3, and so on. The reader will have noticed that our reasoning leading to the general equation (26.r) does not at all depend on the representability of the given grain size distribution by a found-form (algebraic or transcendental) function $f(a)$.

To close this subject it may be instructive to apply our formula (26.r) to some such simple function. Let this be the exponential function, that is, with $\bar{a}$ as unit, by (8),

$$f(a) = e^{-a}.$$

Then, since $[a^m] = \int_0^\infty a^m e^{-a} da = m!$, for any positive integer m, and $\varepsilon n = \bar{a}\varepsilon n$, identical with our previous y, the density formula (26.r) becomes

$$\frac{D}{D_m} = (r+1)y^r \left\{ 1 - \frac{r(r+2)}{r+1}y + \frac{r(r+3)}{2!}y^2 - \frac{r(r+2)(r+3)}{3!}y^3 + \cdots \right\}. \quad (28.r)$$

This should be identical with (9.r) found before by direct integration, that is, with

$$\frac{D}{D_m} = (r+1)\, y^r \frac{\left(1 + \dfrac{y}{r+1}\right)}{(1+y)^{r+1}},$$

and so it is. In fact, the reader will easily verify that the quotient $\left(1 + \dfrac{y}{r+1}\right) : \left[1 + (r+1)\, y + \left(\dfrac{r+1}{2}\right) y^2 + \cdots + y^{(r+1)}\right]$ is identical with the bracketed series in (28.r) for any r. Thus, for example, for $r = 1$, we have

$$\left(1 + \frac{1}{2}y\right) : (1 + 2y + y^2) = 1 - \frac{3}{2}y + \frac{4}{2}y^2 - \frac{5}{2}y^3 + \cdots,$$

identical with the bracketed series in (28.1).

Other examples, such as that of a Gaussian frequency function $f(a)$ may be left to the reader.

High-Speed, Long-Distance Facsimile System.—A test model of a new high-speed, long-distance facsimile system, developed by RCA Laboratories, Princeton, N. J., under contract with the Atomic Energy Commission, has been installed at the Oak Ridge National Laboratory for providing full reference library service to outlying research laboratories.

The new system incorporates several innovations in the field of facsimile reproduction. The reader-transmitter will scan printed copy or drawings on flat surfaces such as book pages and will make direct enlargements of material in small type by any ratio up to 4 to 1. The copy bed can handle individual sheets or books up to 3 in. thick. The signal is transmitted over an ordinary telephone line and the recorder will reproduce clear, highly legible black-on-white copy at a speed of 15 linear inches or 120 square inches per minute.

Operational tests to be started at Oak Ridge immediately will indicate to what extent existing library services at the Laboratory can be expanded without greatly increasing the outlay for new books and particularly scarce and expensive sets of bound scientific periodicals. The system will also prevent possible contamination of books and journals in laboratories using radioactive materials.

At the present time at Oak Ridge more than a score of separate research and production facilities scattered over a wide area require library services. If the new facsimile service proves useful, it may be possible to consolidate many of these library services into larger, more adequate units.

The transmitter is located at the central library at the X-10 site while the only operating recorder is located 8 miles away at the Y-12 site. On the initial test of the system a research chemist at Y-12 requested the complete text of a 2-page article to which he had found a reference in *Chemical Abstracts*. The bound periodical was located in the X-10 library stacks, placed in the transmitter, and a facsimile copy was delivered at Y-12 within 4½ min. after the request was made.

A cathode ray flying-spot scanner at the sending unit is the most important innovation. The 5-in. cathode ray tube directs a tiny spot of light through a focusing lens to "read" the copy in a thin line from left to right. The reflected light from the copy is picked up by a bank of four photomultiplier tubes which convert the varying light impulses into normal electrical facsimile signals.

The copy bed automatically moves the copy forward under the flying-spot cathode ray tube. The length of the scanning line on the copy can be adjusted from 2$\frac{1}{16}$ to 8½ in. by simply turning a knob. This automatically adjusts the lens to maintain the proper focus and the same adjustment changes the speed of the copy bed to maintain the correct scale.

The receiver, or recorder, also incorporates several new mechanical and chemical features to simplify operation and to supply a permanent print of the transmitted material. The electrolytic process used in recording eliminates photo developing and printing and avoids the mess, clogging and corrosion of previous electrolytic methods. The paper is moistened no more than is absolutely necessary, and as it passes out of the machine it is completely dried. Ultraviolet light fixes the chemicals so that neither the printing nor the background will fade. The clogging and corrosive action of the chemical solution is eliminated by keeping separate the two components of the solution until applied to the paper.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS*

NEW SPARK CHRONOGRAPH AND CHRONOSCOPE

The National Bureau of Standards' system for monitoring the precision timekeeping of a group of standard crystal clocks has been further refined by J. M. Shaull and C. M. Kortman of the Bureau staff. This refinement consists of an improved spark chronograph and chronoscope which together record time differences as small as 20 millionths of a second. The new development may be easily applied to checking stability of oscillators and frequency dividers and rating clocks and chronometers over long periods of time. The method is now being applied, in principle, by watchmakers for the rapid adjustment of watches and clocks.

The spark chronograph records time differences of two clocks to one millisecond by linearly sweeping a spark discharge point across the waxed paper strip of a specially designed recorder. The chronoscope uses the visual characteristics of the cathode-ray tube to increase the resolution of the chronograph to 0.02 millisecond. Together these instruments constitute a reference clock with which all other crystal clocks comprising the primary standard, including those of the NBS radio station, WWV, may be intercompared.

The improved spark chronograph includes a single-turn helix wound on a rotating drum driven by a synchronous motor. Beneath the drum is an insulated knife edge over which a strip of waxed paper slowly passes. A high-voltage pulse causes a spark to jump from the knife edge to the nearest point of the helix, perforating the paper, melting the wax, and thus leaving a permanent record. Should the motor driving the drum be supplied by subfrequencies from a standard oscillator while the high-voltage pulse is controlled by another crystal clock, a recorded picture of the relative rates is readily obtained. If the drum-control frequency is equal to the spark-control frequency, each time a spark occurs the rotating drum turns through an angle which is an exact multiple of 360°. Thus, the same point on the helix will be opposite the knife edge, and the record on the waxed paper will be a straight line running vertically up the chart. However, should there be a difference in frequencies, the drum will rotate through a greater or smaller angle, causing a different point on the helix to be nearest the knife edge at the time of the spark. As a result, the record will slope to the right if the clock controlling the spark is running

* Communicated by the Director.

faster, or to the left if the clock is running slower. The difference in rates may be evaluated by measuring the amount of displacement over a given period. If the spark generating equipment is switched, in turn, to each of several clocks, the chronograph provides a convenient method of intercomparing and recording their operation. In practice, a motor-driven switching unit connects each clock to the spark generator every 15 min. In addition, push buttons permit manual checking of a particular clock at any time.

The rotating drum is made of stainless steel; a helical groove is cut into its surface, and a steel spline is soldered into this groove. The synchronous motor drives the drum at a rate of ten revolutions per second, causing the helix to cover a time interval of 0.1 second per sweep. The length of the drum is five inches, and the paper is of the same width; thus 0.001 second is represented by 0.05 in. across the paper chart. The chart is ruled with 10 lines per inch, and values are easily interpolated to the nearest millisecond.

Because the drum rotates at ten revolutions per second, some method is needed to indicate in which tenth of a second the helix is turning. For this purpose, a smaller drum is mounted above the major one and is geared down to rotate at a speed one-tenth as great, and passes over another knife edge which is divided into ten parts. A switch is provided so that the high-voltage pulses can be applied to the smaller drum and the tenths position noted visually.

A pulse-shaping circuit provides the desired pulse for spark generation with different types of input signals. Tests with sine-wave input have shown that the circuit will operate between 10 and 400 cycles when less than ten volts rms is applied, and over a much wider range with greater amplitude.

Since the chronograph records only to 0.5 millisecond, the chronoscope was developed primarily as a vernier device to permit the determination of long intervals with greater accuracy. In this instrument, the output of one crystal clock and frequency divider is used to produce a circular sweep with small, fixed marker dots on the face of a 3-in. cathode-ray tube. A pulse from another crystal clock produces a large bright spot on the sweep. By observing the position of this spot in relation to the marker dots, it is possible to measure relative time changes within a very small fraction of the interval required for one circular sweep. The time base and marker frequencies are obtained from the same frequency dividers that supply the chronograph drive so that the chronograph and chronoscope are locked in time phase just as are the minute and sweep-second hands of a conventional clock mechanism.

The circular sweep is obtained by applying 100-cycle voltages in phase quadrature to the deflection plates of the cathode-ray tube. Thus a 360° sweep is accomplished in 0.01 second. The grid on the

cathode-ray tube is biased below cut-off so that no trace appears on the face of the tube except when a positive pulse is applied with sufficient amplitude to let the tube conduct. A 10-kc. signal applied to the grid therefore produces a circle composed of 100 dots, each 0.1 millisecond apart. Reference points are produced by a 1-kc. sine wave shaped to give negative pulses just wide enough to blank out every tenth one of the 10-kc. dots. Thus the cathode-ray tube shows ten groups of nine dots, each separated by a blank space. The signal to be measured is fed to the chronoscope as a strong positive pulse which places an enlarged dot on the face of the tube. The entire circular sweep represents 0.01 second while the distance between dots corresponds to an interval of 0.1 millisecond. By estimating fifths between the small dots, the position of the larger dot may be determined with sufficient accuracy to measure the change in relative time, as kept by two clocks, within 0.02 millisecond.

For greater resolution a larger cathode-ray tube may be used to increase the span between adjacent markers. For greater accuracy, 100-kc. markers could also be added. Another possibility is the use of a second chronoscope starting with either a 1-kc. or 10-kc. time base and using 100-kc. or 1-Mc. markers to permit higher resolution.

Precise measurements of time and frequency are becoming increasingly important in many technical fields—for example, in long-range radio navigation systems, in the upper range of the microwave region where atomic systems can serve as electronic components, and in basic research in microwave spectroscopy and molecular structure.

SAMPLING OF UPPER LEATHER FOR SHOES

Scientists of the National Bureau of Standards have developed basic information on shoe upper leather which promises to eliminate laborious and wasteful testing of individual hides. The results make it possible for manufacturers and purchasers of leather for shoes to draw up a variety of sampling procedures designed to suit any predetermined set of conditions under which the leather may be selected. This project was inaugurated by the Bureau at the request of the Office of the Quartermaster General as part of a program aimed at supplying better footwear for the Army; it was undertaken by Edwin B. Randall and his associates of the Bureau's Leather Section and John Mandel, a Bureau analytical statistician, with the cooperation of Charles W. Mann of the Office of the Quartermaster General.

The purpose of the Bureau's study was to determine the number of hides which must be taken from a "lot" of leather in order to obtain a representative sample and to discover how many specimens should be taken for test from each side of leather. Material for the investigation consisted of 30 sides of chrome-tanned leather, of medium chrome

and grease contents, split to 5½ ounce weight. From each side 21 blocks were cut out so that corresponding locations on all the selected sides might be compared. The physical and chemical tests chosen for the study were those generally applicable to shoe upper leather that is, tensile strength, elongation, stitch tearing strength, tongue tearing strength, bursting strength, density, water penetration, water-vapor permeability, chromic oxide, hide substance, and grease. For full strength tests, in which a directional effect was expected, specimens were cut in two directions, parallel and perpendicular to the backbone.

One of the first important results was the discovery that physical and chemical properties vary more widely between different locations on the same side than between corresponding locations on different sides. Though this fact had previously been established for heavy leather by workers at the Bureau, the present work is the first demonstration of its applicability to upper leather.

Since, in production, all of the 21 locations of each side cannot be tested, as they were in the Bureau's investigation, the importance of determining the best testing locations cannot be overemphasized. It is clear that a location should be selected whose properties reflect most adequately those of the entire side. This criterion can be understood in various ways. For example, one may search for a location whose properties come closest to the average for the side. Or, on the other hand, a location may be found whose properties, even though they are quite different from the average for the side, bear some constant relation to the latter. On the basis of theoretical consideration and of a careful study of the data, it was concluded that the most desirable sampling location is that for which the properties bear a constant relation to those of the side.

The investigation proved that this criterion of constancy could not be met simultaneously for all properties by the selection of a single location. For each property, however, there are locations for which that property is, except for relatively small fluctuations, a linear function of those of the side. It was shown that for any property the definiteness of this linear relationship can be measured by a well known statistical function: the coefficient of correlation between the value for the selected location and the corresponding average value for the entire side.

On the basis of these considerations, a formula was derived giving a mathematical relationship between the coefficient of correlation of the selected location, the confidence with which the difference in properties between two lots is to be judged, and the number of sides required for that purpose. For each property and for each possible sampling location, the correlation coefficient is calculated between the test result for that location and the average of all test results (for the property considered) for the entire side. The position for which this coefficient

is largest is the most suitable sampling location for the property considered.

As a result of this study, a sampling procedure was devised for upper leather currently under experimental study by the Bureau for the Office of the Quartermaster General. In the selection of the sampling location for a particular test, consideration was first given to the locations from which the fewest specimens would be required to give the desired level of accuracy. However, other factors were considered, such as the desirability of grouping the test specimens in a small area in order to minimize the destruction of leather in other areas designated for storage and wear tests.

Use of only one specimen per side from the proper sampling location, instead of one specimen from each of the 21 blocks, may result in savings of as much as 95 per cent in leather and labor without sacrificing accuracy. The higher the accuracy required, the larger will be the number of sides that must be sampled in order to detect differences between lots.

The test methods used in the work are described in Federal Specification KK-L-311 with two important exceptions. One is the water vapor permeability test[1] devised by Kanagy and Vickers of the National Bureau of Standards. The other is a special adapter developed at the Bureau for use with the Tinius Olsen Testing Machine to measure bursting strength. This adapter was used with the Tinius Olsen Testing Machine instead of the Mullen tester because the latter did not have high enough capacity to break all of the side leather specimens in this experiment.

[1] For further details, see "Water-Vapor Permeability of Leather," *NBS Tech. News Bulletin*, Vol. 34, p. 163 (1950).

THE FRANKLIN INSTITUTE

MINUTES OF STATED MEETING

February 21, 1951

The February Stated Meeting of The Franklin Institute was held in the Lecture Hall on Wednesday evening, February 21, 1951.

The President called the meeting to order at 8:15 P.M. He reported that the minutes of the Stated Meeting for December were printed in full in the January issue of the *Journal of The Franklin Institute*, and that the Minutes for the January meeting were printed in the February issue. As there were no corrections or additions, the Minutes were approved.

The Secretary reported that the following elections to membership have been recorded for January:

Active	34
Associate	39
Student	12
Library Sustaining	6

The total Institute membership as of 31 January was 5,975.

The speaker of the evening, Dr. Martin Summerfield, was introduced by President Nalle.

Dr. Summerfield, who is General Editor of the Aeronautics Publication Program at Princeton University, gave an absorbing talk on the modern developments and future possibilities in rocket propulsion. He presented a survey of these developments, placing particular emphasis upon the fundamental aspects of the modern rocket engine.

As the meeting adjourned, Dr. Summerfield was given a rising vote of thanks.

JOURNAL OF THE FRANKLIN INSTITUTE

The following papers will appear in the JOURNAL within the next few months:

MOON, PARRY AND DOMINA EBERLE SPENCER: Modeling with Light.
DRENICK, R.: The Perturbation Calculus in Missile Ballistics.
CAMPBELL, ASHLEY: Thermodynamic Properties of Reactive Gas Mixtures.
DANFORTH, W. E.: Thoria as a Cathode Emitter.
KOTTLER, F.: The Goodness of Fit and the Distribution of Particle Sizes.

COMMITTEE ON SCIENCE AND THE ARTS

(Abstract of Proceedings of Stated Meeting held Wednesday, February 14, 1951.)

HALL OF THE COMMITTEE,
PHILADELPHIA, FEBRUARY 14, 1951.

DR. RUPEN EKSERGIAN in the Chair.

The following reports were presented for final action:

No. 3213: Collapsible Self-Sealing Fuel Containers.

This report recommended the award of a John Price Wetherill Medal to Reid Berry Gray, of Baltimore, Maryland, "For his development of collapsible and self-sealing fuel cells affording to aircraft greater safety, ability to carry more fuel and, consequently, increased non-stop range of flight, and a proven record to save the lives of aircraft crews."

No. 3231: Franklin Medal.

This report recommended the award of the Franklin Medal to James Chadwick, of the University of Liverpool, Liverpool, England, "In consideration of his outstanding work in nuclear physics, especially his identification of the neutron as a part of the nucleus of the atom."

No. 3076: Yarway Impulse Steam Trap.

This report recommended the award of a Certificate of Merit to John F. McKee, of Philadelphia, Pennsylvania, "In consideration of the development of the design of a compact, simple, rugged steam trap utilizing the principle of the varying pressure in the intermediate chamber between two orifices."

JOHN FRAZER,
Secretary to Committee.

MEMBERSHIP

ACTIVE MEMBERS ELECTED AT THE MEETING OF THE BOARD OF MANAGERS FEBRUARY 21, 1951

ACTIVE FAMILY

Hanley S. Rubinsohn — Joseph W. Seaton

ACTIVE

Alvah B. Adam	Charles G. Douglas, Jr.	William E. Trumpler
Paul E. Almquist	Junius J. N. Gray	George C. Vail
Capt. Ralph S. Barnaby	John Hambach	John A. Waldis, Jr.
C. Stuart Brown	Thomas D. Owens	Daniel J. Walsh
T. L. Cantrell	J. Wood Platt	Paul Weathers
Maj. Aaron E. Carpenter	Samuel A. Plotnick	William P. Werner
Ralph S. Croskey	G. S. Shahinian	Gordon R. Winter, D.D.S.
Albert G. DeGraff	Daniel Snively	Edward F. R. Wood
	Robert V. Tompkins	

ACTIVE NON-RESIDENT

William I. Caldwell — Margaret Murphy

NECROLOGY

Charles Engelhard '13	C. Walker Jones '43	Thomas M. Rector '27
E. C. Franco-Ferreira '44	J. George Klemm, Jr. '08	W. S. Shipley '36
Harry G. Haskell '37	Charles Q. MacDonough '36	Alfred D. Warner, Jr. '37
Thomas H. Huff '45	C. S. Newhall '36	H. C. Yocum '49

MUSEUM

THE ILLUSION SECTION OF THE FRANKLIN INSTITUTE MUSEUM

Everybody is subject to illusions. Illusions are false perceptions and as such create entirely false ideas concerning the outer world. Perhaps the magician represents best the person who makes a living from the study of illusions. It is the magician's business to confound us by creating false perceptions and by creating them under circumstances where we realize they are false. The magician knows that everybody falls victim to his illusions. This demonstrates the fundamental fact that we all have illusions, that there is nothing abnormal in falling prey to an illusion and that the illusion is a consequence of the normal functioning of our sensory apparatus and of the mind served by that apparatus.

The most striking example of an illusion is the "off-axis" room of the Illusion section of The Franklin Institute Museum. This is an ordinary room furnished with a table, chairs and some floor lamps. One end of the room is tilted at an angle of some 12 degrees. The room has two windows and is papered with a vertical stripe wallpaper. There is a small aquarium on the table in which are found some fish. Because the water in the aquarium is at an angle with the table, which we consider to be horizontal, the fish appear to swim uphill.

Upon entering the room the visitor has to walk up-hill. Then despite the fact that the weight on the body is resting on the left foot and the body is in an awkward position, when the visitor sees the room he immediately (within a few seconds) puts himself into the frame of reference of the room and the objects instead of sloping, appear vertical. The illusion rests on the fact that all our lives we have been associated with normal vertical rooms. All the doors and the windows are vertical, the wallpaper is vertical and the floor lamps are vertical. We carry this impression with us at all times. When we are thrown into contact with a sloping room immediately our mind tells us this is not sloping because windows and doors should be vertical and so the sloping lines become vertical. When the visitor looks out of the room into a vestibule which is really vertical, the vestibule appears to be cocked over to one side.

The off-axis room is one of more than 30 illusions collected in the Illusions section. They are of all types except those affecting the sense of touch and smell. There are illusions of form, illusions of motion, color illusions, optical illusions and finally geometrical illusions. The optical and geometrical illusions are the most popular and challenging.

The Phantom Rose is the best example of the optical illusion. Here a rose is projected into a vase. When the visitor passes his hand over the vase it goes right through the rose. The rose, of course, is only an image of a real rose hidden in the base on which the vase is supported.

The geometrical illusions clearly show the influence of background on form. Lines which are straight appear bowed, concentric circles appear as spirals, circles of equal size appear of varying sizes, upright letters appear slanted, parallel lines appear to converge and diverge. Even the moon illusion is illustrated.

The Illusion show represents a showman's excursion in psychology. These illusions are significant to the psychologist for they can be interpreted as the functioning of the various senses. As a matter of fact most of the illusions have been acquired from the top psychologists in the country. Men of the caliber of Dr. Harry Helson, Dr. Edwin H. Boring, Dr. Jozef Cohen, Dr. Malcolm H. Preston and Dr. Hans Wallach have contributed to the section.

LIBRARY

The Committee on Library desires to add to the collections any technical works that members would wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. The average cost for a print 9 × 14 inches is thirty-five cents.

The Library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from 9 A.M. until 5 P.M.; Wednesdays and Thursdays from 2 P.M. until 10 P.M.

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BOOK REVIEWS

SUPERSONIC AERODYNAMICS, by Edward R. C. Miles. 225 pages, illustrations, 16 × 24 cm. New York, McGraw-Hill Book Co., 1950. Price, $4.00.

Here is a text on the now well-explored subject of theoretical supersonic aerodynamics that presents a rigorous mathematical treatment necessary primarily for graduate students or research scientists in the field of aeronautics. The author states that the material presented is essential for further theoretical investigation and for an understanding of current professional literature, and offers a lucid treatment of the mathematical tools required in applications to theoretical aerodynamics. In this respect, this fine book is one of the few welcome additions to the library of the aeronautical sciences.

The author has utilized rigorous mathematical treatment to introduce each subject, and to supplement this presentation, he has included corresponding numerical examples and problems along with their solutions. This is indeed a rare and too often neglected combination of understandable and useable material for the student and the practicing engineer alike. Noteworthy is the minimum usage of the worn out "It is well-known that . . .," since there are very few human brains to which everything about anything is "well-known" or understood. Miles has painstakingly prepared this book with the continuity required for readability, thoroughness and a reasonable amount of sophistication that should satisfy both the keen analytical mind and the so-called handbook designer.

The first of eleven major chapters deals with those fundamental theories of thermodynamics which concern the aerodynamicist. Chapter Two discusses divergence and circulation theory and is followed by the definition and derivation of the potential function and the potential equation in the several coordinate systems in Chapter 3. Chapter 4 contains the origin of characteristics theory in a system of linear algebraic equations and an exposition of the Prandtl-Busemann graphical method for two-dimensional flow. The linear theory of two-dimensional flow is treated in Chapter 5, and the linear theory of axially symmetric flow in Chapter 6. Chapter 7 covers the treatment on the subject of oblique shock waves and Chapter 8 is devoted to cones in supersonic flow including the traditional Taylor-Maccoll solutions. The graphical-computational method of characteristics for axially symmetric supersonic flow is treated in Chapter 9 and the last two chapters are devoted to potential flow in the hodograph plane and the comparisons of adiabatic and shock flow in two demensions.

SAMUEL M. BERKOWITZ

STELLAR EVOLUTION, by Otto Struve. 259 pages, illustrations, plates, 16 × 24 cm. Princeton, Princeton University Press, 1950. Price, $4.00.

Lectures have their place in the scientific society for they often provide the stimulus for a formalization of a field of study. *Stellar Evolution* is the result of that method of exposition. The author is Dr. Otto Struve, one of the most prolific writers in astronomy today. As Director of both the Yerkes and McDonald Observatories he has had his finger on the pulse of astrophysics for almost two decades and this work illustrates the tremendous grasp Dr. Struve has of the subject.

When the reviewer took his first course in astronomy, more than 20 years ago, the text book used devoted roughly 100 pages out of more than 500 to stars, nebulae, galaxies and cosmogony. Here is a book of almost 250 pages devoted exclusively to a narrow field involving some aspects of the stars. Here is a criterion of the advance of astrophysics in the past two decades and Dr. Struve has been in vanguard.

Stellar Evolution is divided into three sections. Part I deals with the chemical and physical properties of the stars and the necessary groundwork is given for an understanding of the conclusions reached by Dr. Struve. The author shows that the elements in the atmospheres

of the stars—giants, super giants, dwarfs, and white dwarfs have approximately the same cosmic abundances. A similar composition is found for the interstellar gas, bright diffuse nebulae and the planetary nebulae. The evolution of the hot giant stars and their time scales are discussed. Here is contained a good deal of speculation which has a very definite place in astronomy today.

Part II discusses some problems of stellar evolution. Here is found a resume of the nuclear cycle to account for the energy of the stars. The formation of stars and the various courses of evolution are related.

Part III deals with the origin and development of close double stars. Here is collected in a single publication a compendium of information concerning eclipsing binaries and spectroscopic binaries.

Stellar Evolution is a magnificently written book and will serve for a long time as a source book for astrophysicists working on related problems. The book is very nicely edited with three indices: one for authors, the second for subject and the third for the stars is the one which will be appreciated most by the worker in the field. The book could have contained a bibliography to complete it.

It is a stimulating book and is highly recommended for both the professional and amateur astronomer.

I. M. LEVITT

TECHNOLOGICAL APPLICATIONS OF STATISTICS, by L. H. C. Tippett. 189 pages, diagrams, 15 × 24 cm. New York, John Wiley & Sons, Inc., 1950. Price, $3.50.

This book is the outgrowth of a series of lectures delivered by Mr. Tippett at the Massachusetts Institute of Technology. The author, a leading English statistician, does not assume that his readers have any previous knowledge of statistics. He treats the fundamentals of the subject, and illustrates them by numerous examples drawn from his experiences in applying statistics in industry.

The book is not to be thought of as a text in basic statistics, but as Mr. Tippett himself states: "The book is perhaps best regarded as an introduction and companion to a systematic text-book or course of study in applied statistics. The exposition is developed from particular examples, and the development is more through arithmetical procedures than through mathematical proofs." As such it should be of more interest to the industrialist than to the pure statistician. A word of caution to the uninitiated, however. In any statistical analysis the assumptions involved and the interpretation of the results are of such importance that they should be left to the experienced statistician.

Though the book will not make the reader an experienced statistician, it will give him a valuable insight into the possible applications of statistics, as seen by one well qualified to write on this topic. Mr. Tippett is the author of several books on statistics, and is responsible for the compilation of *Tippett's Random Sampling Numbers*, a useful collection of random digits for those dealing with problems of random sampling.

D. B. HOUGHTON

APPLIED NUCLEAR PHYSICS, by Ernest Pollard and William L. Davidson. Second Edition, 352 pages, 15 × 23 cm., drawings and photographs. New York, John Wiley & Sons, Inc., 1951. Price, $5.00.

New fields experience their greatest growth during their early years. These are the early years of applied nuclear physics and, in view of the spectacular accomplishments of the past eight years, a book with this title published nearly a decade ago would require considerable editing and expansion. Preserving their book as a concise picture of practically all phases of nuclear science, the authors have accomplished the revision by adding approximately one hundred pages revealing in particular information on self-sustained nuclear chain reactions.

Nearly of equal importance in representing major advances is the progress in building accelerators during the 1942 to 1951 period. Much effort has been expended in attempts to build ever higher energy devices. Some of the advances have grown out of radar techniques

as has Alvarez' proton accelerator at the University of California, Hansen's microwave, electron accelerator at Stanford and others. The 6-Bev giant bevatron under construction at the University of California, financed by the Atomic Energy Commission, is described and a drawing shows its extensive components.

The reviewer noted additional emphasis on electronic circuitry for particle detection and counting. A new appendix is devoted to neutron diffraction and some interesting possibilities of a spectrograph using slow neutron beams made "monochromatic" by diffraction from single crystals. Success with this technique at Oak Ridge is evidenced by a striking photograph of neutron diffraction by a rock-salt crystal. A new chapter titled Elementary Pile Theory shows analytic relations and principles of pile construction. A detailed description covering the historic Chicago pile, the Clinton, Hanford, Argonne Laboratory and recent power piles is given.

Owing to the circumstances surrounding the first publication of this book, security regulations and a practical lack of information about applications of nuclear physics as we now know it, the second edition is sufficiently different to be considered largely a new publication. It should be of interest to all technically trained professionals from the standpoint of its lively historical coverage as well as a clear presentation of basic facts relating to nuclear science.

C. W. HARGENS

THE SOLUBILITY OF NONELECTROLYTES, by Joel H. Hildebrand and Robert L. Scott. Third edition, 488 pages, diagrams and tables, 15 × 23 cm. New York, Reinhold Publishing Corp., 1950. Price, $10.00.

From the fact that the first edition of this book by Prof. Hildebrand appeared in 1924, it may be safely concluded that the author is in an excellent position to present an authoritative account of the present status of the theory of nonelectrolyte solubility. From the additional fact that the first edition was essentially qualitative in nature, it may be further concluded that tremendous effort has since been expended by the scientific world in the exact treatment of the subject, with considerable help from the senior author himself.

The most striking impression made by the first third of this book is the vigorous attempt to present the more acceptable mathematical treatments now extant on solubility phenomena. After a general discussion of ideal and nonideal solutions, consideration is given to the fundamental or molecular analysis of the liquid state. Here the authors were apparently beset with the difficult, but common, problem of how much mathematics to present in order to attain an acceptable degree of clarity. This problem has been treated fairly well, but by no means with optimum results. The book continues with a strong thermodynamic presentation of the entropy, heat and free energy of mixing.

The remainder of the chapters on miscellaneous general theory treat polarity, related "association," vapor pressures of binary liquid solutions and gaseous mixtures. The justification for the presence of the latter chapter lies in the relations between the thermodynamic properties of such mixtures and their solution properties when in the liquid state.

Successive chapters then take up the solubility of liquids in gases, solids and liquids, respectively. These form a very interesting section and present considerable portions which are the authors' original thoughts and work. Significant use is made of a solubility parameter δ, characteristic of a given chemical species and which can be used to semi-quantitatively predict solubility behavior of this compound in a desired environment, the δ of which is also known. The results are encouraging enough to hope that efforts will be continued to refine this method.

The remaining chapters include a systematic treatment of solid and metallic solutions, and a new chapter on high polymer solutions.

The ACS Monograph is an extremely desirable survey of the present status of nonelectrolyte solubility, and should be indeed useful as a guide to research men in the field.

A. L. MYERSON

THE PRIMEVAL ATOM, by Canon Georges Lemaître; translated by Betty H. and Serge A. Korff. 186 pages, 13 × 20 cm. New York, D. Van Nostrand Co., 1950. Price, $3.00.

The subject of cosmogony has had a history replete with spectacular advances and recessions. Dating from Archimedes, the foremost philosophers of the time have advanced theories which temporarily held the limelight only to fade to a dim shadow in the background. Giants in the cosmogonical field like Buffon, Kant, Laplace, the contemporary de Sitter, Jeans and Eddington and now Lemaître have studied the problem for a possible solution. *The Primeval Atom* is the latest book on this fascinating subject.

Canon Lemaître states, "The purpose of any cosmogonic theory is to seek out the ideally simple conditions which could have initiated the world and from which, by the play of recognized physical forces, that world, in all its complexity, may have resulted." To account for the universe he assumes that in the distant past there came together for a single instant a primeval atom which was an isotope of a neutron. In that instant, because of the instability of the atom, there was a tremendous explosion in which the pieces of the primeval atom were exploded into space. The breaking up process continued until the pieces became atomic in nature and the expansion has been going on ever since.

As a result of this single explosion Canon Lemaître attempts to explain the formation of stars and nebulae, the density of matter in space, the origin of cosmic rays and finally the size and shape of the universe.

The book is well written and carefully thought out. It consists of five chapters in which the first four lay the background for the understanding of the fifth which is really the contribution which the author makes to the science. At the conclusion of the book is an appendix into which are packed the mathematical notes and explanations which would have a discouraging effect on many readers if introduced in the text.

Chapter One deals with the ideas of space beginning with Archimedes. There is a discussion of distances encountered in the universe and the question of an infinite universe is explored. He shows how astronomy has extended the scale of cosmic formation and the chapter is concluded with the pressing problem of the recession of the distant galaxies.

Chapter Two deals with the expansion of space and demonstrates how the major difficulties to an understanding of space can be removed by recourse to non-Euclidian geometry and the theory of relativity.

Chapter Three deals with the evolution of celestial objects ranging from stars to galaxies. One disquieting feature which this reviewer has found here is the insistence of the long time scale running into 10 or 100 billion years. If these time scales are correct there would be no evidence of differential galactic rotation, and the galaxy should now be behaving like a gas nebula which it obviously isn't. Also there is an objection to the long time scale for the stars. Astronomers like Spitzer and Whipple will not go along with a long time scale for the supergiant stars.

Chapter Four is a very lucid and readable account of the old cosmogonies and the last chapter is devoted to an exposition of the Lemaître hypothesis.

The Primeval Atom is an absorbing book which throws new light on the present cosmogonic theories. As Canon Lemaître indicates, this is not the last word on the subject and for that reason it will be interesting to see what the author does with the observational material which will be forthcoming in the next 15 or 20 years from the new 200-in. telescope on Mt. Palomar.

I. M. LEVITT

THE CHEMISTRY OF THE NONBENZENOID HYDROCARBONS, by Benjamin T. Brooks. Second edition, 615 pages, diagrams, 16 × 24 cm. New York, Reinhold Publishing Corp., 1950. Price, $12.00.

In writing the first edition of this book, published in 1922, one of the objects of the author was to show the close relationships which hold generally throughout the chemistry of the nonbenzenoid hydrocarbons. The author then felt that the chemistry of the nonbenzenoid hydrocarbons had been neglected in most general textbooks of organic chemistry. In this

second edition the author admits that the field has grown so greatly that it is difficult to present an adequate review and discussion of it. If one wishes to obtain a general picture of the present state of petroleum chemistry or the industrial processes for the manufacture of various products from petroleum and natural gas, then this book should be very useful. There are numerous references to the literature, including the patent literature.

Some parts of the book are not as up-to-date as others, for example, the chapter on oxidation of paraffins. In addition, this reviewer fiinds an occasional misquotation of the literature, for example, in referring to a paper of Walsh on page 152, the incorrect statement is made that cool flames appear in the oxidation of methane. One cannot find detailed critical discussions of the mechanisms of the thermal decomposition nor of the oxidation of paraffin hydrocarbons nor of the action of catalysts in this book, but one can find information as to the types of processes used in the utilization of petroleum.

In general the book is a review of the chemistry of the nonbenzenoid hydrocarbons with the emphasis on industrial processes and as such has a definite place on the reference shelf of anyone working in the petroleum field. There are good subject and author indices which aid one in referring to the original literature.

WILLIAM E. SCOTT

PUBLIC HEALTH ENGINEERING, by Earle B. Phelps and others. Volume 2, 213 pages, illustrations, 14 × 22 cm. New York, John Wiley & Sons, Inc., 1950. Price, $4.00.

This second volume devoted to public health deals ostensibly with food and the principles of sanitation in food production, handling, and distribution. Actually the text material is not at all so general. Of the eight highly descriptive chapters, four are given over to the subject of milk production, pasteurization, milk plant processes and equipment, and plant inspection and control; one to shellfish and their live storage facilities; one to public eating and drinking places; and one to garbage disposal from the point of view of rodent control, and one to food control administration.

To this reviewer, the book seems shallow and void of statements of basic principles of public health sanitation as applied to food. It is felt that fully one half of the material could have been omitted with no loss. On the other hand, perhaps a more appropriate title indicative of the emphasis placed on milk would be more satisfactory.

S. CHARP

BOOK NOTES

INDUSTRIAL SOLVENTS, by Ibert Mellon. Second edition, 758 pages, diagrams, 16 × 24 cm. New York, Reinhold Publishing Corp., 1951. Price, $12.00.

With information on some 380 solvents, this second edition provides a useful source of information on industrial solvents. The text covers physical data and commercial uses and applications with numerous graphs and tables for specific and comparative figures. A new chapter has been added on the safe handling of solvents while chapters on plasticizers and graphic expression and interpretation have been omitted.

THE IDENTIFICATION OF MOLECULAR SPECTRA, by R. W. B. Pearse and A. G. Gaydon. Second edition, 276 pages, 20 × 28 cm. New York, John Wiley & Sons, Inc., 1950. Price, $8.50.

Much new material has been added in this practical work on the identification of molecular spectra in the wave-length region from 10,000 to 2000 Å. Generally, new data have been included up to 1947 and in some cases as late as November 1949. More references have been given in view of their usefulness for other purposes than identification. Four new plates containing twenty-six enlargements have also been added.

BYPRODUCTS FROM MILK, by Earle O. Whittier and Byron H. Webb. 317 pages, 16 × 24 cm. New York, Reinhold Publishing Corp., 1950. Price, $6.00.

The authors have gathered together in one volume the material relating to the use of dairy byproducts, available in such varied sources as Federal and state bulletins, patents,

and technical journals. A description of the physical and chemical characteristics of milk, skim milk, whey and buttermilk is given. Many different products are treated including condensed, dried, canned and bakery products. Flow charts are used and theoretical discussions are included where they seemed necessary for the understanding of the principles on which the manufacturing procedures are based.

Extensive lists of references have been included for those desiring to pursue any particular subject further.

YEARBOOK OF THE TEXTILE INSTITUTE, No. 3, 1950–1951. 246 pages, 15 × 24 cm. Manchester, The Textile Institute, 1950. No price given.

Primarily devoted to information about the Textile Institute and its members, this publication does contain other useful information. Worthy of note are a list of textile terms and definitions, contributions to a list of recommended textile terms, a list of textile associations and other organizations of interest to the textile researcher; and a list of textile literature.

STATIC AND DYNAMIC ELECTRICITY, by William R. Smythe. Second edition, 616 pages, diagrams, 16 × 24 cm. New York, McGraw-Hill Book Co., 1950. Price, $8.50.

The principal change in this edition is the adoption of rationalized mks units throughout the text, which has been further modernized by changes in nomenclature. Some chapters have been extensively rewritten and numerous problems have been added in both static-field and electromagnetic-wave chapters.

A MANUAL FOR THE SLIDE RULE, by Paul E. Machovina. 78 pages, diagrams and illustrations, 15 × 23 cm. New York, McGraw-Hill Book Co., 1950. Price, $0.75(paper).

A text prepared for use of the scale on modern duplex-type slide rules. The relationship of logarithms to the slide rule is emphasized and the memorizing of "rules" is minimized. Problem sheets have been included.

KINEMATICS OF MACHINES, by George L. Guillet and A. H. Church. Fifth edition, by Austin H. Church, of "Guillet's Kinematics of Machines." 299 pages, illustrations, diagrams, 14 × 22 cm. New York, John Wiley & Sons, Inc., 1950. Price, $4.00.

Professor Church has revised Guillet's book while at the same time endeavoring to avoid interfering with its "teachability." Chapters extensively revised are those on velocity and acceleration in plane motion and on gears. Other changes have been made and uniform and consistent symbols have been adopted throughout.

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ELLICE McDONALD, DIRECTOR

A BIBLIOGRAPHY ON SONIC AND ULTRASONIC VIBRATION: BIOLOGICAL, BIOCHEMICAL AND BIOPHYSICAL APPLICATIONS

BY

GEORGE M. NAIMARK, JANE KLAIR AND WILLIAM A. MOSHER

AUTHOR INDEX

A

ANON....136, 280, 370, 371, 388, 417, 418, 419, 459, 503, 552
ABBOTT, C. E.... 4
ACKERMAN, E.... 553
ADAM, M.... 209
ADRIAN, E. D.... 164
AGATO, J. N.... 389
AKIYAMA, S.... 99
ALLEN, C. H....420, 460, 475
ANDERSON, E. O.... 100
ANDERSON, T. F....393, 461
ARING, C. D.... 308
ARMSTRONG, J. J. P.... 31
ASHTON, W. H.... 165
AUDOUIN.... 421
AUDOUIN, A.... 452
AUDOUIN, MME.... 421
AULER, H.... 309

B

BACHMANN, J. A.... 137
BALDES, E. J....16, 17, 18, 25
BANDEIRA DE MELO, J.... 372
BARTH, G.... 462
BATEMAN, J. B....247, 284
BATT, W. G.... 422
BAUMGARDT, E.... 101
BEARD, P. J.... 166
BECK, F. F.... 248
BECKWITH, T. D....32, 102
BÉKÉSY, G. v....210, 249, 250, 463
BENZ, F.... 464
BERGMANN, L....103, 104, 167
BERITOFF, I....14, 15
BEUTHE, H.... 281
BIANCANI, E....40, 43, 49, 61, 62, 79, 143, 172, 173, 174
BIANCANI, H....40, 43, 49, 61, 62, 79, 143
BIERMAN, H. R.... 571
BIRD, F. F.... 554
BLUMBERG, H.... 122
BOGG, S.... 461
BOGOSLOVSKII, A. I....138, 211
BÖNI, A.... 560
BONGIOVANNI, A. M.... 383
BONTCHKOVSKY, V. F.... 9
BORCILA, I.... 92
BORN, H....232, 445
BOROWSKY, S.... 336
BOVAIN, A.... 24
BOUMAN, H. D.... 80
BRADFIELD, G.... 555
BRADISH, C. J.... 390
BREGADZE, A....14, 15
BROCKLEHURST, T.... 373
BROGI, G.... 423
BROHULT, S....139, 251
BROWN, B. B.... 295
BROWN, E. P.... 282
BROWN, M....306, 310
BRÜNER, H.... 465
BURRIS-MEYER, H.... 311
BUSHNELL, R. J....499, 500
BUSSI, L....341, 512

C

CALKINS, H. E....247, 284
CAMPBELL, H.... 504
CANIGGIA, A.... 423
CARLIN, B.... 505
CARROTE VOGA, M.... 391
CERNY, A.... 312
CHAMBERS, L. A....33, 41, 45, 50, 51, 52, 63, 81, 82, 83, 105, 106, 107, 108, 109, 128, 140, 141, 142, 158, 168, 169, 179, 212, 213, 214, 223, 247, 252, 283, 284, 313, 392
CHAPMAN, E. M.... 337
CHERNIUK, E.... 215
CHICK, A. J....322, 323, 347
CHILD, C. M.... 135
CHORINE, V.... 424
CHRISTENSEN, R. J....64, 76
COERMANN, R....170, 216, 253
COHEN, S. C.... 393
CONGER, A. D.... 466
CORBEILLE, C....16, 17, 18, 25
CULLER, E. A.... 65
CUMMINGS, S. B., JR.... 387
CURRY, B.... 506
CYRIAX, E.... 467
CZARNETSKY, E. J.... 187

D

DALINO-DOBRONOLSKY, L. B.... 338
DANILOV, V. I.... 217

* Continued from this JOURNAL, February, 1951, p. 279.

DART, E. E. ... 394
DAVIS, H. ... 314, 339, 344, 468
DEL GROSSO, V. A. ... 548
DELLA MONICA, F. ... 218
DELORENZI, E. ... 254
DEMETER, K. J. ... 219
DEMIDOV, A. ... 222
DENIER, A. ... 395, 396, 397, 398, 399, 425, 469
DE ROBERTIS, E. ... 470
DE SOTO MORALES, F. ... 353
DEUTSCH, V. ... 92
DEVAUX, P. ... 340
DIESSBACHER, M. ... 42
DI MACCO, G. ... 171
DITTMAR, C. ... 507, 508
DOGNON, A. ... 40, 43, 49, 61, 62, 79, 143, 172, 173, 174, 426, 509
DRENNOVA, K. A. ... 220
DRUETT, H. A. ... 389
DUSSIK, F. ... 427
DUSSIK, K. T. ... 315, 427
DWORKIN, S. ... 48
DYROFF, R. ... 354

E

EFIMOV, V. V. ... 221, 222
EICHHORN, R. D. ... 567
ELDREDGE, D. H., JR. ... 447, 489, 556, 557
ELIASZ, A. ... 91
ELLFOLK, N. ... 576, 577
EL'PINER, I. E. ... 471
ELY, J. O. ... 535
ERDOS, T. ... 496, 497
EULER, H. v. ... 352
EVANS, S. M. ... 472, 510, 511

F

FANUCCHI, F. ... 341, 512
FERGUSON, G. H. ... 255
FERGUSON, L. K. ... 313
FIEDLER, G. ... 428
FILITTI-WURMSER, S. ... 206
FINCH, G. ... 65
FINKLE, A. L. ... 473
FLORSTEDT, H. ... 256
FLOSDORF, E. W. ... 51, 52, 83, 106, 107, 109, 223, 257, 258, 283
FÖRSTER, F. ... 144
FORBES, A. ... 5
FORBES, T. W. ... 311
FORRESTER, J. S. ... 224, 297
FRANKE, E. K. ... 474, 558
FREEHAFER, J. E. ... 285
FRENCH, C. S. ... 175, 259, 400, 570
FRENCH, L. A. ... 559
FRENZEL, H. ... 53, 84
FREUNDLICH, H. ... 44, 54, 145, 176
FRINGS, H. ... 429, 460, 475
FRITZ-NIGGLI, H. ... 560
FROHRING, W. O. ... 308
FRY, W. J. ... 561
FURBACH, E. ... 281

G

GABLER, F. ... 476
GAEDE ... 286
GAINES, N. ... 30, 41, 45, 46, 82
GALAMBOS, R. ... 287, 316, 513, 569, 573
GANTVOORT, W. F. ... 166
GARAY, K. ... 477
GARDINER, M. R., JR. ... 361
GARROTE, V. M. ... 401
GAULT, R. H. ... 110
GELDARD, F. A. ... 66, 260
GHOSE, S. C. ... 562
GIACOMINI, A. ... 514
GILLINGS, D. W. ... 176
GILMER, B. v. H. ... 66, 85, 111, 288
GIRARD, P. ... 177
GOHR, H. ... 261, 317
GOLDBERG, A. ... 134
GOLDSTEIN, A. ... 337
GOLDSTEIN, G. ... 478
GOODFELLOW, L. D. ... 55, 67, 374
GOUGEROT, L. ... 426
GOULD, J. ... 289
GRABAR, P. ... 375, 424, 430, 448, 450, 479, 515, 530, 536
GREEN, D. E. ... 413
GREGG, E. C., JR. ... 355, 563
GRÜTZ, O. ... 516
GRUNEWALD, R. ... 290

H

HAAS, E. ... 342, 356
HABER, P. ... 91
HAGGENMILLER, S. ... 543
HAM, G. P. ... 357
HAMBLETON, J. ... 523
HAMRE, D. ... 517
HARDY, H. C. ... 431
HARISAKI, Y. ... 274, 343, 376
HARRIS, T. N. ... 313
HARTMANN, F. ... 480
HARTREE, E. F. ... 437
HARVEY, E. B. ... 11
HARVEY, E. N. ... 10, 11, 19, 20, 21, 26, 33, 34
HAUFF, E. ... 178
HAUSSER, I. ... 518
HAWKINS, J. E., JR. ... 344
HAYTHORN, S. R. ... 288
HENLE, G. ... 179, 262, 415
HENLE, W. ... 179, 262, 415
HERČÍK, F. ... 318
HERRICK, J. F. ... 519
HERSH, A. H. ... 27
HEUBERGER, A. ... 416
HINSBERG, K. ... 53, 84
HINTZELMANN, U. ... 432, 574
HIRSH, I. J. ... 569, 573
HIRSH, S. K. ... 569
HOGEBOOM, G. H. ... 564
HOLLAND, G. ... 112
HOLSTE, A. ... 144
HOLT, A. S. ... 400
HOPWOOD, F. L. ... 35, 36, 225, 268
HORIKAWA, M. ... 113, 114
HORSLEY, C. B. ... 433
HORTON, J. P. ... 565
HORVATH, J. ... 354, 358, 402, 403, 481
HORWOOD, M. P. ... 565
HRDLIČKA, M. ... 318
HSI, E. ... 506
HUANG, C. H. ... 291

HÜTER, T. 482, 520
HUNTER, D. 377
HUNZINGER, W. 521, 566
HYDÉN, H. 434

I

ICHIKAWA, F. 305
INOUÉ, T. 294
ISTOMINA, O. 86, 115

J

JAKOVLEV, P. A. 263
JENEF, H. D. v. 292
JENKINS, R. 571
JOHNSON, C. H. 12
JOHNSON, M. 435
JOLY, M. 483
JUNG, F. 319
JUNGHANNS, H. 146

K

KADONO, M. 320
KAIBARA, T. 522
KAKUSUI, T. 226
KALOYEREAS, S. A. 436
KAMBAYASHI, H. 182, 183
(See KANBAYASI, H.)
KAMINSKI, M. 530
KANBAYASI, H. 184
(See KAMBAYASHI, H.)
KARL, H. O. 321
KARRER, E. 27
KASAHARA, M. 147, 148, 149, 180, 181, 182, 183, 184, 226, 227, 228, 264, 265
KAUSCHE, G. A. 293
KAWASHIMA, K. 148
KAYE, G. W. C. 116
KEILIN, D. 437
KEMP, W. N. 404, 406
KHENOKH, M. A. 550
KIMBALL, A. C. 223, 257, 258
KIMURA, O. 87
KINNEY, V. C. 6
KIRBY, C. K. 546
KITANO, H. 294
KLEIN, E. 484
KNUDSEN, V. 88
KOBAYASHI, R. 71
KOELSCH, F. 89
KOEPPEN, S. 359
KOJIMA, K. 125
KONISI, K. 149
KOSTEN, C. W. 150
KOSTER, H. F. 489, 557
KRAKOV, S. V. 117
KRANTZ, J. C., JR. 248
KREJCI, L. E. 438, 523
KRESS, F. 485
KRUEGER, A. P. 295
KRÜGER, F. 185
KUBO, T. 296
KÜSTER, E. 524
KUSANO, S. 118
KUZNECON, S. I. 338
KVASNIKOV, E. I. 266

L

LACKMAN, D. B. 187, 231
LAMPORT, H. 567
LANGNER, F. W. 297
LANGNER, P. H., JR. 224, 297
LAPORTE, R. 378
LAUFER, A. R. 568
LAWRENCE, N. S. 570
LEGALLEY, D. P. 267
LEITCH, J. L. 438
LEPESCHKIN, W. W. 525
LEVAVASSEUR, G. 410, 452, 453, 458
LEWIS, D. 345
LIECHTI, A. 312
LIKHATCHOFF, ... 151
LION, K. L. 554
LIPPERT, S. 439, 486
LIU, S.-C. 39, 68, 78
LIVE, I. 333, 360, 361, 379, 405
LLIBOUTRY, L. 362
LOEBELL, H. 37
LOEWENTHAL, H. 268
LOISELEUR, J. 378, 380
LO MONACO, G. 90
LONG, C. A. 504
LOOMIS, A. L. 7, 8, 10, 11, 19, 27, 34
LOVELL, G. D. 298
LURIE, M. H. 344
LYNN, J. G. 322, 323, 346, 347, 348, 363

M

MACKEY, W. L., JR. 360
MAIER, N. R. F. 381
MAJER, V. 119
MALKIEL, S. 440
MARINESCO, N. 69, 177, 186
MARK, H. 382
MARTIN, W. 6
MARTISCHENJA, A. 134
MATSUDAIRA, M. 70
MATTEUCCI, E. 152
MAUZE, J. 424
MAYBERRY, W. 153
MAYER, K. 120
MCFARLANE, A. S. 225, 229
MCFARLANE, M. G. 229
MCKENZIE, A. A. 441
MCKINNON, C. R. 406
MCLAUGHLIN, A. I. G. 377
MEDOFF, H. S. 383
MEISTER, F. I. 154
MEISTER, F. J. 409
MELDGAARD, A. 364
MELTZER, S. J. 1
MEYER, W. 442
MICHON, P. 230
MICKLE, H. 487
MILLER, A. E. 323, 347
MILLER, G. A. 569
MILLER, R. H. 5
MILNER, H. W. 570
MINCH, V. A. 565
MINNICH, D. E. 121
MINOGUCHI, G. 269
MO OCH DOMSJO AKTIEBOLAG 488
MOREL, J. 530
MORELLI, E. 299
MORGAN, C. T. 290
MORGAN, I. M. 231
MORROW, P. L. 571

MUDD, S. 187, 231
MÜHLETHALER, K. 416
MÜLWERT, E. 300
MULLER, D. 364
MURANO, K. 324
MURMANN, H. 155
MYERS, R. J. 122

N

NAKAGAWA, T. 457
NAKAHARA, W. 71, 77
NAKAMURA, M. 301, 302
NAN, S. S. 226, 264, 265
NARUSE, T. 147
NEAL, D. 559
NEUWEILER, N. G. 349
NEWCOMER, E. H. 499, 526
NEWMAN, H. F. 567
NICHOLAS, R. 336
NIELSEN, D. M. 384
NIKITIN, L. V. 123
NODL, F. 527
NOLTINGK, B. E. 528

O

O'CONNOR, J. 5
OESTRICHER, H. 558, 572
OGATA, S. I. 182, 183, 184, 227, 264
OLSON, A. R. 12, 32
ONO, S. 270, 271
OSTER, G. 443
OSTROVSKII, E. 86, 115
OSWALD, K. 232
OTT, G. J. 6
OWADA, K. 124
OYAMA, H. 72
OZAKI, M. 125

P

PÄTZOLD, J. 232, 444, 445
PAGNIEZ, P. 325
PAIC, M. 91, 92
PARKER, W. 381
PARMEGGIANI, L. 446
PAROW, E. 233
(See PAROW-SOUCHON, E.)
PAROW-SOUCHON, E. 326, 492
(See PAROW, E.)
PAREY, W. 47
PARRACK, H. O. 447, 489, 557, 572
PATTERSON, G. W. 267
PÉREZ, J. J. 407
PERLICK, A. 156
PERRY, K. M. A. 377
PERWITZSCHKY, R. 56
PETTIT, H. 187, 231
PFANKUCH, E. 293
PINKERTON, J. M. M. 529
PLOYÉ, M. 490
PLUZNIK, E. E. 217
POHLMAN, R. 233, 234, 235, 256, 365, 491, 492
POLLICE, F. 327
POLOTSKII, I. G. 278, 408
PONZIO, M. 126
POPPEN, J. R. 473
PORTER, B. H. 272
POSTLETHWAITE, F. 366
POWELL, R. D. 400
PRUDHOMME, R. O. 430, 448, 479, 515, 530, 536
PUGH, N. J. 449, 531
PUMPHREY, R. J. 127
PUTNAM, T. J. 346, 348, 363

R

RÁCZ, I. 477
RAHN, O. 385
RANDALL, R. 532
RANQUE, J. 410
RAWDON-SMITH, A. F. 127
REGGIANI, M. 299
REIHER, H. 157, 409
RESTARSKI, J. S. 386
RICHARDSON, E. G. 533
RICHTER, R. 233
RINDFLEISCH, H. 465
RIVERS, T. M. 158
ROBERTS, A. 534
ROCKETT, F. 441
RODEWALD, W. 73
ROFFO, A. E., JR. 303
ROGOWSKI, F. 44, 54
ROÏKH, I. L. 350
ROMMEL, O. 239
ROSENBLITH, W. A. 513, 569, 573
ROSS, M. H. 535
ROSS, O. A. 328
ROTH, L. M. 493
ROUYER, M. 375, 450, 536
RUBIN, E. 236
RUDNICK, I. 420, 460, 475
RÜHLICKE, K. 543
RUSKA, H. 293

S

SAKIYAMA, T. 147
SALAMAN, M. H. 225
SALB, O. G. 329
SAMISCH, R. 64
SASAGAWA, K. 188, 273
SATA, N. 237, 238, 274
SATO, A. 70
SAUTET, J. 410, 451, 452, 453
SCHALLER, F. 537
SCHECTER, H. 189
SCHERP, H. W. 128
SCHLIEPHAKE, E. 93, 275
SCHLITTLER, E. 57
SCHLUNGBAUM, H. 492
SCHMID, G. 129, 239, 574
SCHMITT, F. O. 12, 23, 28, 470
SCHNEIDER, W. C. 564
SCHOENAERS, F. 494
SCHOLTZ, H. G. 330
(See SCHOLZ, H.-G.)
SCHOLZ, H.-G. 495
(See SCHOLTZ, H. G.)
SCHORR, H. 351
SCHREUER, E. 454
SCHREY, A. 130
SCHULTES, H. 53, 84, 112, 300
SCHULTES, T. 300
SCHUMANN, F. 313
SCHUMB, W. C. 331
SCHUSTER, K. 155

SCHWABE, W. W. 575
SCHWARTZKOPFF, J. 538
SCHWARZ, 240
SCHWEIWECHMANN, B. E. 241
SCRIBNER, E. J. 295
SEIDL, F. 539
SERGENT, C. 407
SETZEPFAND, W. 94
SHIBUYA, H. 131
SHIMAZU, R. 132
SHROPSHIRE, R. F. 455, 456, 540, 541
SIEMENS-REINIGER-WERKE, ERLANGEN 276
SIERING, Q. 411
SIMONOT, Y. 509
SKARZYNSKI, B. 352
SKOLNICK, A. 190
SKUDRZYK, E. 542
SMADEL, J. E. 158
SMITH, E. W. 141, 252
SMITH, F. D. 95
SMITH, F. W., JR. 412, 413
SNELLMAN, O. 496, 497
SNOW, M. L. H. A. 6, 13, 29
SÖLLNER, K. 44, 54
(See SOLLNER, K.)
SÖRENSEN, C. 281
SOKOLOV, S. Y. 96, 133
SOLLNER, K. 367, 368
(See SÖLLNER, K.)
SONTAG, L. W. 97
SPECHT, W. 543
SPERLING, F. G. 379, 405
ŠPRINDRICH, J. 318
SPUR, B. 336
STÄGER, A. 191
STANLEY, W. M. 74
STARKERMAN, A. S. 350
STEPHEN, W. A. 332
STERCKX, R. 98
STERN, K. G. 478
STEVENS, S. S. 304
STRAUSS, H. 498
STROZECKA, L. I. 277
STUART, W. S. 544
STUBBS, E. L. 333, 360, 361, 369, 379, 405
STUMPF, P. K. 412, 413
STURM, R. E. 329
SUEDA, M. 159, 160, 161, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 242, 243
SÜLLMANN, H. 521, 566
SUENAGA, T. 125
SUSUKI, S. 305
SUTHERLAND, G. F. 48
SWEENY, L. 438, 523
SZALAY, A. 58, 75
SZENT-GYÖRGYI, A. 59

T

TACHIBANA, T. 334, 457
TAKAGI, T. 181
TAKAHASHI, W. N. 76
TAKAHASI, G. 335
TARNEAUD, J. 202
TATUMI, M. 149, 184
TEMKIN, J. 60
TEVEROVSKIĬ, B. M. 217
THEISMANN, H. 480, 524
THIELE, E. H. 545
THIELE, O. W. 317
THIEME, E. 203
THORNEY, M. J. 375
THORNTON, C. S. 387
THURSTON, E. G. 546
TIMM, C. 537
TITOV, A. I. 220
TORBETT, J. W. 6
TSUGE, S. 204
TYLER, J. M. 162

U

UEDA, R. 246
UGLOW, W. 134
UHLMEYER, B. 28
URAZOVSKIĬ, S. S. 278, 408

V

VAN WAGTENDONK, W. J. 551
VELICOGNA, A. 414
VERWEY, W. F. 545
VIOLLIER, G. 521, 566
VIRTANEN, A. I. 576, 577
VOET, J. 91
VOĬNOVITCH, I. 515
VON GIERKE, H. 572, 578
VON WITTERON, W. W. 558, 572
VUILLET, J. 410, 452, 453, 458

W

WACHSMANN, F. 462
WALKER, E. A. 546
WALLACE, R. F. 97
WALLACE, R. H. 499, 500, 526
WANNOW, H. A. 163
WARNER, A. R., JR. 532
WEAVER, C. E. 102
WEDEKING, T. 261
WEIL, A. J. 169
WEISSLER, A. 547, 548
WESENMEIER, K. 205
WETMORE, P. W. 532
WHITE, S. Y. 501
WIEN, M. 2
WIENER, M. 415
WIERCINSKI, F. J. 135, 244
WIETHE, C. 549
WILBRANDT, W. 312
WILCOX, H. H. 579
WILD, J. J. 559, 580
WILKINS, R. 137
WILLIAMS, O. B. 30
WILLIAMS, R. L. 279
WINDLE, W. F. 579
WINTERS, B. C. 461
WOLMAN, I. J. 336
WOITE, H. 309
WOLFERS, F. 38
WOLFERS, C. 365
WOOD, R. W. 7, 8, 245
WOOLF, W. L. 311
WU, H. 39
WUHRMANN, K. 416
WULFF, V. J. 561
WURMSER, R. 206
WYT, L. 427, 502

Y

YACORZYNSKI, G. K. 306, 310
YAKOVLEV, P. A. 207
YAMAHA, G. 246
YAOI, H. 77
YEN, A. C. H. 68, 78
YERKES, R. M. 3
YOSHIDA, K. 182, 183
YOSHINARE, T. 180
YOSIO, K. 184

Z

ZEISS, E. 208
ZEIT, W. 510, 511
ZHUKOV, I. I. 550
ZHYCHKOVA, A. D. 221
ZILL, L. P. 551
ZITTLE, C. A. 422
ZOTTERMAN, Y. 307
ZWEMER, R. L. 322, 323, 347

SUBJECT INDEX

Alcoholic beverages 137, 141, 252
Animals 5, 14, 16, 17, 18, 164, 190, 192, 193, 194, 195, 196, 197, 198, 199, 200, 220, 222, 228, 242, 243, 269, 287, 381, 383, 386, 387, 429, 475, 538, 573, 578, 579
  body weight 161, 193, 194, 195, 196, 198, 199, 242
Bacteria 19, 30, 50, 68, 77, 78, 92, 98, 99, 102, 107, 109, 169, 175, 182, 219, 224, 240, 259, 266, 267, 295, 297, 338, 375, 380, 385, 392, 413, 424, 450, 455, 456, 459, 517, 532, 536, 541
  Brucella 327, 333, 360, 361, 369, 379, 405
  Escherichia coli 393, 565
  Hemophilus pertussis 223, 257, 258, 545
  Streptococcus 187, 231, 247, 268, 284, 328
  Tubercle bacilli 378, 485
Bibliographies 189, 417, 506, 569
Biological aspects 7, 8, 10, 11, 26, 38, 41, 44, 49, 53, 59, 61, 62, 65, 79, 80, 90, 91, 126, 130, 135, 136, 143, 144, 166, 170, 171, 172, 173, 186, 188, 192, 193, 194, 195, 196, 197, 198, 199, 215, 218, 273, 318, 322, 323, 341, 349, 355, 408, 417, 454, 460, 465, 468, 471, 475, 501, 512, 514, 519, 539, 542
Blood 113, 114, 131, 335, 423, 448, 480, 525, 543, 566, 571
  blood cells 1, 10, 22, 124, 147, 299, 312, 319, 509, 543, 571
  blood pressure 18, 192, 200, 383
Books 38, 143, 167, 186, 245, 505
Brain 346, 348, 363, 513, 579

Camphor 125
Cancer and tumors 71, 248, 309, 354, 358, 399, 402, 403, 481, 507, 508, 516, 518, 527, 559, 571
Carbohydrates 204, 270, 271, 274, 350, 423
Cardiac responses 17
Cellulose 296, 357, 416, 488, 547
Cells and tissues 20, 21, 24, 33, 34, 40, 41, 124, 132, 233, 235, 246, 248, 254, 303, 309, 329, 363, 365, 434, 445, 472, 476, 481, 482, 487, 508, 510, 511, 516, 526, 527, 554, 561, 564, 580
Chemical aspects 52, 59, 81, 101, 119, 129, 130, 133, 172, 186, 324, 331, 362, 367, 368, 382, 408, 411, 421, 436, 448, 452, 457, 477, 479, 521, 528, 529, 530, 547, 548, 576, 577
Coagulation 12, 39, 78
Colloids 69, 87, 113, 114, 145, 163, 176, 185, 237, 238, 274, 343, 367, 368, 376, 539, 570
Conditioned responses 48
Crystallization 217

Denaturation 51, 106, 448, 566
Depolymerization 58, 75, 139, 203, 205, 239, 251, 350, 430, 457, 523, 535, 550
Diagnosis 315, 337, 395, 396, 397, 398, 399, 425, 426, 427, 546, 559
Diffusion 84
Disintegration 179, 212, 224, 229, 247, 268, 270, 271, 284, 297, 299, 312, 333, 357, 360, 361, 369, 375, 378, 379, 392, 400, 405, 413, 416, 424, 455, 456, 470, 487, 488, 496, 497, 509, 554, 564, 567, 570
Dispersion 82, 456, 457

Ear 24, 60, 164, 220, 287, 302, 316, 344, 556, 578
  hearing 42, 56, 57, 241, 289, 339, 463, 538
Emulsions and emulsification 11, 122, 185, 279, 504
Enzymes 63, 64, 70, 131, 140, 180, 205, 206, 342, 356, 413, 422, 437, 479, 515
Ergosterol 317
Estrous cycle 160
Extracts and extraction 107, 169, 175, 257, 259, 268, 283, 413, 424, 536, 540, 545
Eyes and vision 117, 138, 207, 208, 211, 263, 277

Fat 122
Fish 33
Fungi 305, 320, 515, 522, 524
Food 100, 156, 168, 178, 435
  milk 108, 142, 149, 165, 180, 213, 214, 219, 279, 280, 282, 336

Gels 54
General 35, 36, 45, 46, 72, 73, 88, 89, 96, 101, 103, 104, 116, 120, 150, 153, 167, 189, 191, 209, 245, 255, 275, 278, 285, 286, 290, 301, 321, 340, 390, 417, 418, 431, 441, 484, 486, 503, 505, 528, 533, 555, 562, 563, 568, 574
Genetics 27, 466, 499, 500, 526

Healing of wounds 201
Heart muscle 21
Heat effects 7, 49, 174, 192, 243, 492 509
Histamine wheals 112
Hormones 118
Humans 2, 9, 47, 97, 151, 210, 216, 253, 311, 366, 409, 439, 463, 473, 474, 492, 558, 572, 573, 578

Insects 4, 27, 33, 121, 127, 410, 451, 453, 458, 490, 493, 537, 560
  larvae 4, 12, 33, 410

Lethal effects 12, 22, 28, 102
Liver 113, 204, 564

Measuring devices, sound and vibration 157, 329, 389, 562
Medicine 29, 256, 261, 276, 321, 351, 353, 371, 373, 377, 391, 401, 404, 406, 414, 444, 446, 462, 464, 467, 469, 471, 473, 495, 512, 539, 549, 552
Metabolism 134, 204, 434
Micromanipulation 23

Nerve....123, 249, 434, 467, 470, 561
Nucleic acid....478, 523, 535

Oxidation....72, 125, 421, 479

Pharmacy and pharmacology....353, 411, 442
Photomicrography....34
Physical aspects....7, 8, 95, 130, 136, 186, 475
Physiological aspects....13, 14, 15, 116, 154, 162, 192, 193, 194, 195, 196, 197, 198, 199, 209, 221, 222, 230, 298, 304, 314, 345, 370, 388, 447, 489
Planaria....244
Plants....86, 115, 246, 364, 465, 500, 575
chloroplasts....11, 400, 570
Poisons....118, 334, 551
Polymers....382, 430
Propagation of sound waves....520, 558
Proteins....39, 51, 83, 106, 109, 113, 114, 139, 175, 237, 251, 259, 293, 343, 407, 438, 448, 480, 496, 497, 521, 525, 530, 536, 548, 566
albumin....39, 51, 83
hemocyanin....139, 251
gelatin....237, 343
Protoplasm....10, 11, 12, 23
Protozoa....12, 22, 23, 92, 494
paramecia....43, 105, 551, 553

Respiration....16, 124, 192

Skin....71, 256
Sonic oscillators....72, 123, 155, 232, 292, 300, 311, 390, 433, 481, 534, 544, 554
magneto-strictive....46
quartz....272, 276, 323, 347, 412
siren....420, 562
Spermatozoa....159, 179, 262, 387
Spinal reflexes....6
Spleen....25, 114
Sterilization....41, 385
Stomach....381

Tannin....238
Teeth....386
Therapy....31, 37, 42, 56, 57, 93, 152, 202, 233, 234, 313, 325, 326, 330, 359, 395, 396, 397, 425, 428, 432, 454, 491, 495, 498, 502, 520, 534
Toxins....181, 226

Ultrasonic centrifuge....177

Vaccines....77, 158, 184, 225, 227, 229, 294
Vibratory sensitivity....3, 55, 66, 67, 85, 94, 110, 111, 154, 190, 236, 250, 260, 288, 306, 307, 308, 310, 374, 409, 538
Viruses....76, 158, 184, 225, 229, 295, 461, 536
encephalitis....264, 291
influenza....128, 415, 517
poliomyelitis....128, 183, 228
rabies....265
tobacco mosaic....74, 293, 440, 443, 483
Vitamin C....148, 149

Water purification....281, 384, 449, 531
Workers....9, 146, 151, 162, 241, 372, 373, 377, 394, 419, 473, 557

Yeast....32, 98, 102, 332, 352, 517

CURRENT TOPICS

Cosmic Ray Mystery Held Near Solution.—Strong evidence has been developed that the sun may be the No. 1 source of the mysterious cosmic ray "barrage" which keeps the earth under continual bombardment.

This announcement was made recently by the National Geographic Society and the Bartol Research Foundation of Philadelphia's Franklin Institute in an interim report on the results of research work conducted in Canada last year at the top of the atmosphere above the Hudson Bay outpost of Fort Churchill.

Dr. Martin A. Pomerantz, Bartol physicist directing the program, said he was encouraged to believe that further study of the data obtained, coupled with additional research, would confirm the evidence developed to date.

Solution Long Sought

Ever since the existence of cosmic rays first came under study early in this century, science has been puzzled as to the origin of these energy-charged particles which bombard the earth day and night from outer space.

Some have theorized that they may be the result of a cosmic cataclysm from which our universe ultimately emerged. Others had them hurtling, unexplained, from the vast void of infinity. A third belief is that they might be generated by the interplay of magnetic fields existing in the stars and nebulae. And there have been those who suspected the answer lay in the sun—that it was a gigantic manufacturing plant for these sub-atomic projectiles.

An important and long sought missing link in the chain of knowledge that might resolve this riddle has been reliable information on the magnetic qualities of the sun.

Old Theory Exposed

In research work at Fort Churchill during 1949 Dr. Pomerantz secured data which exploded the widely held theory that primary cosmic rays in the low energy category never reach the earth because they are deflected at very large distances by a permanent solar magnetic field.

The 1950 work at Fort Churchill served to double-check Dr. Pomerantz's previous findings that the existence of a permanent solar magnetic field of great magnitude is not compatible with the formerly accepted hypothesis that cosmic rays travel over distances which are very large compared with the 93 million miles between the earth and sun. The low energy rays that any such field would have "bent" away from the earth continued to go through the atmosphere's "ceiling" as they did a year ago.

The data compiled by instruments sent aloft by a train of free balloons to heights of 20 miles or more strongly suggests, Dr. Pomerantz reported, that the sun may be the source of virtually all the cosmic radiation reaching the earth. Still unsettled is the question whether the sun may have a permanent magnetic field of an intensity so low as to escape observation, or that

it possesses a fluctuating field. Dr. Pomerantz pointed out, however, that neither type field would prevent the emission of solar generated rays, and, in act, a varying field could provide a mechanism for accelerating charged particles up to cosmic energies. In principle, the operation would be similar to that of a man-made atom-smasher.

New Data Revealed

In this connection, the physicist from Swarthmore, Pa., made known some previously undisclosed information which has just emerged from analysis of balloon flight records obtained in this continuing program of cosmic ray investigation. The information supports the theory that certainly some of the cosmic ray particles are "manufactured" on the sun.

On May 10, 1949, there occurred a solar flare, or chromospheric eruption, of the highest possible rating on the scale of the International Astronomical Union. The following day, as part of a research program already in progress, Dr. Pomerantz sent up a regular instrument flight to the "roof" zone of the atmosphere. Practically all the scientifically measured phenomena normally accompanying such a solar outburst meanwhile had long disappeared with the subsiding of the flare.

About 19 hours after the solar eruption occurred, however, Dr. Pomerantz's instruments began recording an abrupt increase of about 15 per cent in the intensity of cosmic rays at altitudes of between 95,000 to 100,000 feet. Simultaneous measurements of solar radio noise by the Radio-Astronomy Observatory at Cornell University revealed an unusually high intensity in the radio signals which are continually emanating from the sun and are detected by special radar receivers. This is the first evidence of such a correlation.

"From a statistical point of view," the physicist commented, "the odds against the fortuitous observation of such an increase are roughly 6000 to 1."

Greater Increase Likely

The instrument rig—a quadruple-coincidence Geiger counter train—used on this occasion was inclined at an angle of 60 degrees, which means that the rays it recorded had to travel a greater distance through the smaller residual air path above the apparatus than those that would be detected by a rig in a vertical position.

Since cosmic rays dissipate their energy as they travel through space, it follows that a vertical instrument rig might have recorded an even greater increase in the intensity of radiation at this time.

During the period of the sharply stepped up cosmic ray activity near the top of the atmosphere, ground measuring stations at various points of the earth recorded nothing unusual. The depth of the disturbance's penetration into the atmosphere could not be precisely established, but at altitudes lower than 55,000 feet readings for normal and post-flare periods were found to overlap.

The cooperation of the National Bureau of Standards is being enlisted by the National Geographic Society and Bartol Foundation to facilitate a systematic future study of the cosmic ray disturbances. The fact that a solar flare or eruption apparently "telegraphs" intensification of cosmic ray activity a

day in advance will give scientists sufficient notice to get set to observe these disturbances henceforth.

Details of the plans for this new study program will be announced later, the National Geographic Society said.

Research in Canada

In the course of the 1950 research program on the shores of Canada's Hudson Bay, a point far north in geomagnetic latitude, Dr. Pomerantz conducted 32 ballon-borne instrument flights, up to altitudes as high as 110,000 feet.

An important feature of the work was that in a number of flights the instruments were rigged horizontally so that they could be "triggered" only by rays travelling in paths parallel to the earth's surface.

Discussing the nature of these horizontal rays, Dr. Pomerantz said they evidently were "kicked off" in a flat plane direction by rays of low energy after the mother rays entered the atmosphere. High energy rays, he observed, tended to travel in a straight line toward the earth, propagating "children" in the form of protons, neutrons, mesotrons (or mesons), and other heavy nuclear fragments as they break down in the course of their journey through the atmosphere.

The observations indicated that the newly detected group of particles which reaches the "top of the atmosphere" at Churchill but not at Swarthmore, Pa., possesses energies so relatively low that it could not have arrived according to the previous theories of cosmic radiation.

The research at Fort Churchill also developed valuable material on the energy and other properties of both primary and secondary rays. This information is expected to prove an important laboratory aid in unlocking still further secrets which the mystery of cosmic radiation now holds.

A rocket fuel-handling suit developed by the Aero Medical Lab., Air Materiel Command, protects personnel against accidental exposure to such propellants as red fuming nitric acid and aniline, provides interior cooling and an air supply to prevent asphyxiation. The outer clothing consists of vinyl-impregnated Fiberglas hood and coverall, butyl rubber boots and vinyl-coated cotton gloves, with plastic visor in the hood. The air-cooling method involves a ventilating harness attached to a nylon suit worn under the coverall, with a 50 foot plastic tube delivering air to the harness and hood, thus eliminating need for a respirator. A water cooled system has also been devised, which replaces the air-delivery tube with a demand-type breathing apparatus.

Televised Microscopy.—Significant extension of the range, power and versatility of the light microscope by use of special electronic eyes of the television camera, instead of the human eye, was demonstrated recently by scientists of Princeton University and the RCA Laboratories Division.

The new technique of televised microscopy, since it enables the interchanging of television camera tubes made sensitive to specific wave lengths of light, gives considerably sharper contrast than heretofore available, according to Dr. A. K. Parpart, chairman of the Princeton Department of Biology. Dr.

Parpart has tested the experimental RCA industrial television equipment in biological research since last April.

The television-microscope combination, Dr. Parpart said, also has the advantages of making possible (1) the study of many components of living cells normally visible only after killing and staining and (2) the direct observation of motion of, and within, these cells at high magnifications. Even without the specially sensitized tubes a high degree of contrast enhancement can be obtained by means of the variable light level controls on the television receiver screen.

Though the RCA televised microscopy equipment has been used primarily for research at Princeton, Dr. Parpart said that it had proved convenient for showing specimens to several persons simultaneously in a conference group. It has also been used successfully in large classroom demonstrations by Dr. Harry Fulbright, former Princeton physics professor, in two otherwise difficult microscopic demonstrations—the Millikan oil drop experiment and the demonstration of Brownian motion in smoke particles.

Adaptation of the RCA industrial television system for microscope work was done by L. E. Flory and J. M. Morgan, of the RCA Laboratories research staff. The equipment was made available to Princeton University by RCA Laboratories. Dr. V. K. Zworykin, Vice President and Technical Consultant of RCA Laboratories, directed the development of the RCA industrial television system.

The experimental installation consists of a laboratory microscope mounted beneath an RCA industrial television camera, which is no larger than a personal 16-mm motion picture camera. The televised microscopic scene is transmitted by cable to a standard receiver-monitor placed nearby.

At the heart of the industrial television camera is a remarkably small and sensitive pickup tube—the Vidicon. For microscopy, the Vidicon can be sensitized with materials which make it receptive to a particular narrow band of wave lengths. For the model used by Dr. Parpart, a red-sensitive tube and a violet-sensitive tube have been provided. RCA research engineers are developing tubes which may extend the range of the microscope's vision into the infra-red and ultra-violet regions. The microscope can also be equipped with a binocular viewer and a second television camera so that two selective tubes scan the microscopic scene at the same time.

With the red or violet tube, Dr. Parpart explained, it is possible to select a narrow wave length band for study of a particular cellular material whose light absorption characteristics lie in that band. The degree of contrast between various chemical components within the cell, he said, is much superior to that previously gained by the tedious method of photographing the specimen through color filters. In fact, he added, some granules in living cells have been brought out this way for the first time.

Many biological specimens, such as granules of certain red blood cells, can at present be studied only after they have been stained, he said. With televised microscopy, the appropriate tube will make the specimen stand out clearly without staining, he said, explaining that staining often either kills a specimen or, in some instances, a specimen must be killed before it will absorb the stain.

Dr. Parpart pointed out that the new technique enabled examination of either slow or rapid motion of material under a microscope at magnifications which formerly could have been "watched" only by motion picture photography. This method offered no effective way of monitoring what the camera was shooting and required such an intense light source that living material was either killed or injured, he said. With the low light levels needed for televising the microscopic scene, living material can be examined for many hours without damage.

Mr. Flory said that enlargement of the image up to 15 to 20 times through the television system made for ease of viewing and made the equipment particularly adaptable for classroom or conference use. Even larger enlargements are feasible by projection of the image onto a screen, he said.

Commenting on his research with the RCA equipment in a recent letter to Dr. Zworykin, Dr. Parpart stated: "It has been possible to observe certain microscopic particles in cells in active Brownian motion that have not been observed before; it has been possible to expose various egg cells, red cells and plant cells to light of different wave lengths and thus be able to study at a particular wave length, details of cellular structure that are not clear or not observable visually.

"For example, in eggs of the sea urchin, the violet-sensitive tube will pick out the echinochrome granules and exclude yolk and protein granules. The latter granules are well defined under the red-sensitive tube while the echinochrome granules are apparently absent. This ability to see details by selective absorption at narrow wave lengths is a very real advantage."

Dr. Parpart has used the equipment primarily in studies of a wide variety of marine life at the Marine Biological Laboratory, Woods Hole, Mass. Besides its value in other branches of biology, the technique should be of importance in medicine, chemistry, geology, physics and other fields of research.

The Vidicon tube was developed at RCA Laboratories by Dr. Paul K. Weimer, Stanley V. Forgue and Robert R. Goodrich, under the supervision of Dr. Albert Rose. Research engineers of RCA credited with the development of the overall industrial television system are Richard C. Webb and J. M. Morgan. Special tube faces used in the Vidicon for the new technique of televised microscopy were evolved by A. D. Cope.

Science Adviser for Department of State.—Dr. Joseph B. Koepfli, of the California Institute of Technology, has been named Science Adviser in the Department of State. Dr. Koepfli's appointment follows consultation with a number of the nation's leading scientists.

Creation of the Office of the Science Adviser was proposed by Dr. Lloyd V. Berkner, Special Consultant to the Secretary, in his report, "Science and Foreign Relations", made public last June. Dr. Koepfli, on leave from the Institute, will assist in developing the Department's international science program recommended in this report.

A major responsibility of the Science Adviser and his staff will consist of helping to shape U. S. foreign policies and of advising on the administration of programs in their science aspects. In assuming this responsibility, Dr. Koepfli's office will draw freely upon the competence of other scientists and will seek to bring about the closest teamwork between American scientists and

government officials in policy formulation and administration. His office will serve as the central point in the Department of liaison with the National Science Foundation, the National Academy of Sciences, the National Research Council and other public and private science organizations.

The Office of Science Adviser will be bolstered by the placement in important foreign service posts of top-flight American scientists. These science staffs will keep Dr. Koepfli abreast of developments of science abroad and will facilitate the flow of scientific information between this country and friendly nations.

Dr. Koepfli brings to his new post more than twenty years of achievement in organic chemistry which has won him the respect and confidence of scientists here and abroad. His researches have been particularly in the isolation, structure determination and synthesis of alkaloids, in the development of antimalarial drugs and the field of plant hormones.

A native Californian, Dr. Koepfli received his A.B. and A.M. degrees from Stanford University, and his Ph.D. degree from Oxford University, England, in 1928. He was Research Fellow at the California Institute of Technology the following year, and from 1929 to 1931 served on the faculty of Johns Hopkins University School of Medicine. He has been a Research Associate at the California Institute of Technology since 1932.

During World War II, Dr. Koepfli was engaged in research carried out under the Committee on Medical Research of the Office of Scientific Research and Development, and during 1948 served as a Science Attache at the U. S. Embassy in London.

False fur fashioned from nylon is being tested by Air Materiel Command laboratories. Shortage of wolf fur used to trim and line parkas, flight jackets and caps for arctic operations caused Air Force to turn to synthetics, with a resulting product that looks and wears as well as anything the wolves can turn out—and at 1/5 the cost. "Synthetic wolf," still in the experimental stage, is now being tested at 65° below zero. The Air Force is also testing synthetic mouton which indicates that sheep, too, are being outclassed by the laboratories and that critical shortages in either sheep or wolves will not prevent Air Force personnel in the arctic from being well clothed. The synthetic pelts, manufactured by the George W. Borg Corporation of Delavan, Wisconsin, can be cut in any shape or form and are easier to work with than natural furs.